THE ARTILLERY OF THE FUTURE AND THE NEW POWDERS

LONGRIDGE

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BY

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PREFACE.

It may seem strange, that at a time when all nations appear to have come to the conclusion that their ordnance is approaching perfection, I should choose as the title of this little work, 'The Artillery of the Future.'

I have adopted the title deliberately, and the work itself must be my justification.

For many years I have been at variance with gun-makers and artillerists on the subject of the increase of ballistic effect. Whilst I have advocated high pressure in strong and comparatively short guns, they have gone in the opposite direction, reducing the pressure, increasing the weight of charge and the length of the gun, until at the present moment guns of 40 to 50 calibres in length, working with a maximum pressure of about 17½ tons per square inch, have come into use.

The importance of the principles which I have so long advocated become still more evident, now that the new powders have attracted so much attention, and this I have endeavoured to show in the following pages. The pamphlet 'Smokeless Powder,' which I published last year, was little more than a forecast of what, to my mind, was looming in the not very distant future, and the conclusions therein arrived at have been greatly strengthened, and. indeed, confirmed by further investigations, based upon much more extensive data, especially as regards the Nobel powder.

I am not sanguine that these conclusions will be speedily adopted, or even favourably considered, by the ordnance authorities in this country.

It has taken me about thirty years to convince them that my views about gun construction were correct, and that the

use of coiled wire, and the separation of the material for resisting the bursting and the longitudinal strains, were important features in gun construction.

It will probably be the same again. The construction of long guns calculated for low pressures will probably be continued and further millions spent until we once more find that by the adoption of stronger guns and high pressure some other nation has distanced us in the artillery race.

The conclusions I have arrived at are not mere opinions, they are the result of careful investigations, and they appear to me to be of sufficient importance to justify me in submitting them, as I now do, to the candid appreciation of gunmakers and artillerists.

In doing so I fully agree with an old writer who says, "He who opposes his own judgment against the opinion of the times ought to be backed with unanswerable truths; and he that hath truth on his side is a fool as well as a coward if he is afraid to own it because of the currency or multitude of other men's opinions."

J. A. Longridge.

Grève d'Azette, Jersey,
June 1, 1891.

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ERRATA.

At bottom of page 68, *for* $1 + 492° + \cdot 34 = 167 \cdot 28$ units,
read $1 \times 492° \times \cdot 34 = 167 \cdot 28$ units.

And page 72, line 7 from bottom, *for* "in" *read* "or."

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APPENDIX.

THE ARTILLERY OF THE FUTURE, AND THE NEW POWDERS.

CHAPTER I.

1. In August 1890 I published a small pamphlet on 'Smokeless Powder, and its Influence on Gun Construction.'

2. This was based upon the very scanty information which was then at my disposal. More recently further information has been published in the 'Revue d'Artillerie' of September 1890, of the results of firing with Nobel's smokeless powder at Essen and Meppen, between 1st October 1889 and 1st March 1890.

3. The guns used were sixteen in number, of calibres varying from 5 cm. to 21 cm., or 1·968 inch to 8·24 inches, and of lengths varying from 13 calibres to 40 calibres. From these guns 468 rounds were fired, and the velocities at given distances from the muzzle, varying from 164 to 264 feet, and the maximum pressures recorded.

4. The powder, known as R.G.P. (Rauchloses Geschütz-Pulver), was in grains varying from 0·0395 to 0·393 inch in thickness, and had been in store about five months.

5. The velocities were measured by two chronographs, and the pressures either by Rodman's apparatus or by the crusher gauge, and in some of the larger guns the two were used concurrently.

6. The cartridges in some cases were of brass attached to the projectile, in other cases separate from the projectile,

but in metallic cases, and in the larger calibres of 4·74 inches and upwards, in the ordinary silk bags.

7. The tables given in the 'Revue d'Artillerie' contain the following particulars:—

Date of firing.
Calibre, length, and weight of gun.
Dimension of grains of powder.
Weight of projectile.
Weight of charge.
Gravimetric density.
Velocity of projectile.
Maximum pressure.

8. These elements enable us to arrive at some conclusions of considerable importance with regard to the ballistic qualities of this powder, and presumably of other powders of analogous nature, such as the French B.N. and the English Cordite.

9. Although the published information regarding these two powders is very scanty, I will endeavour in a subsequent part of this paper to make use of it in a comparison between their relative ballistic power and that of the Nobel powder.

10. At present I proceed to the investigation of the effect of the Nobel powder, as influenced by the various ballistic elements, such as weight of projectile and charge, size and grain of powder, calibre and length of gun, and size of chamber or air spacing.

This investigation must only be looked on as approximative, inasmuch as the information given is in some respects imperfect, but the results arrived at will probably be not without interest to Artillerists.

11. The general problem as regards the ballistic effect of a powder is to determine the muzzle velocity and the maximum pressure when a given charge is fired behind a projectile of given weight in a gun of given dimensions.

There is, however, another problem of great importance, viz. to determine the variation of pressure in the chase of a

gun, whilst the projectile is passing from its initial position to the muzzle.

It is not enough to know the maximum pressure which exists in the vicinity of the powder chamber. It is required to know the pressure corresponding to each position of the projectile, so that the requisite strength of chase at that point shall be determinable.

I do not pretend to have solved this problem, but only to have pointed out the limits which the pressure cannot exceed, and which, therefore, constitute a safe guide in designing the chase of a gun.

At the same time it will be found that the hypothesis on which the method is founded leads to formulæ which agree very fairly with the actual results of experiments, as regards the muzzle velocity and the maximum pressure under the given ballistic elements.

12. The method of investigation adopted is no doubt open to criticism. It rests to a certain extent upon hypothesis and assumptions, and does not possess the analytical value of M. Sarrau's method, but it will be found to give approximately correct results as regards the new powders, and moreover is applicable to estimating the pressures along the chase of a gun more directly, and perhaps with greater accuracy, than has been done heretofore.

13. This is a question of very great importance in gun construction, and it appears to be still much misapprehended by artillerists and gun-makers, judging from the weakness of the slender chases adopted in the long guns now in vogue.

14. The knowledge which we at present possess of the pressures existing in a gun corresponding to different positions of the projectile in its passage to the muzzle, is chiefly derived from the indications of crusher gauges placed at different points in the chase of an experimental gun.

15. But, as has been shown by Sarrau and Veille in their important and valuable essay, 'Étude sur l'emploi des manomètres d'écrasement,' 1883, the indications of the crusher gauges are by no means so easily interpreted as is

generally supposed, since the amount of crushing is not altogether and simply proportionate to the crushing force, but depends very considerably on its mode of application, on the mass of the piston, and other conditions.

This matter is of such importance that I shall devote a small space to it in the following chapter.

CHAPTER II.

16. The interpretation of the amounts of compression of the copper cylinders used in these gauges is called by Messrs. Sarrau and Veille the "Tarage." We have no exact equivalent for this word in English, and indeed, it does not appear in Littré's Dictionary, but as used by Sarrau and Veille it means the experimental determination of the relation between the force applied and the consequent permanent compression of the cylinder, and perhaps it may be best designated by the word "Verification."

17. Consequently the estimation of the force applied presupposes the previous experimental Verification of the indications of the instrument. For this purpose cylinders of the same material and dimensions as those used in the crusher gauges are crushed by forces of known magnitude, and tables are thus established showing the correlation between a certain series of applied forces and the corresponding compressions of the cylinders.

Now the method of Verification is variable.

18. (*a*) The crushing may be effected by a constant force of known magnitude acting without initial velocity.

19. (*b*) The method employed in France, by the Artillerie de la Marine, is by the use of Joessel's balance, by means of which cylinders of copper are crushed between two surfaces of steel. The arm of the balance, loaded with a given weight at a certain distance from the axis of rotation, is made to act rapidly on the cylinder, by removing a support which sustains the loaded arm at rest, and guides it during a portion of its motion so as to give to the effective force a determinate law of variation.

20. Messrs. Sarrau and Veille also make use of Joessel's balance, but in two distinct methods.

(*c*) The cylinders are crushed slowly and progressively by small quantities until they support the load without further compression.

(*d*) The weight is slowly and gradually moved along the arm of the balance, so that the force is gradually and uniformly increased from zero to a given determined amount.

In each method the force on the cylinder attains (though by different laws) a final value T called the "Force of Verification" (Tarage), and the corresponding compression ϵ is measured. The series of correlative values of T and ϵ constitute the "Table of Verification."

21. The two methods employed by Sarrau and Veille give identical results, but the compressions for given value of T are less than those given by the method adopted by the Artillerie de la Marine. For a given value of T, ϵ is greatest when the force is suddenly applied, and least when it is applied slowly and uniformly.

22. It is generally admitted, that when the apparatus acts under the varying pressure of a gas, the maximum value of the pressure P is equal to the "Force of Verification" corresponding to the measured compression.

It might be thought that this is self-evident, but it is only approximate, for it is subordinate, at any rate, to the choice of the method of Verification, because the same force gives different values of ϵ according to the method of application of the force.

By elaborate and very careful experiments, Messrs. Sarrau and Veille found

23. (1) that with ordinary powder, in a close vessel, the amount of compression depends neither on the mass of the piston (within the most extended limits of practical use) nor on the mode of development of the pressure, as characterised by the duration of the time of compression.

24. (2) That to the compressions produced (under the same conditions of application), by pistons of different base

area, the corresponding "Forces of Verification" are proportional to the area of the bases.

25. Consequently, for ordinary powder in close vessels, the maximum pressure is proportional to the "Force of Verification" corresponding to the measured compression.

26. In order to decide whether the process of Verification adopted gives results not only *proportional*, but also *equal*, to the maximum pressures, Messrs. Sarrau and Veille compared their results with those obtained by Colonel Sebert by means of his "Accelerograph" and they found that they were in perfect accordance.

27. They therefore concluded, that for ordinary powders in close vessels, and under the conditions of Verification adopted by them, the calculation of the maximum pressure from the compression of the cylinders is perfectly legitimate.

28. But this conclusion does not hold good with regard to pressures produced by explosives of a more rapid action.

With such explosives, even when the conditions of the charge and the maximum pressure remain the same, the amount of compression varies very considerably with the mass of the piston and with the rate of development of the gas.

29. They therefore sought to analyse theoretically the circumstances attending the motion of a piston crushing a cylinder under the action of a force which was a function of the time.

The result of this investigation showed that in the case of a slow explosion, the measure of the maximum pressure is the "Force of Verification" corresponding to the full value of the compression ϵ, whilst with a very rapid explosion it is the "Force of Verification" corresponding to one-half the value of ϵ.

30. In fact Messrs. Sarrau and Veille show that the relation between the pressure and the compression is expressed by the formula

$$P = \kappa_0 + \frac{\kappa\,\epsilon}{1 + \phi\left(\frac{\tau}{\tau_0}\right)}. \qquad (1)$$

in which

κ_0 and κ are constants;

τ is the time elapsed from the origin to the moment of maximum pressure;

τ_0 the duration of the compression under a constant force, acting without initial velocity, on a piston whose mass is m and $\tau_0 = \pi \left(\frac{m}{\kappa}\right)^{\frac{1}{2}}$.

ϕ a function, which when $\frac{\tau}{\tau_0}$ = zero is equal to unity and which decreases rapidly as $\frac{\tau}{\tau_0}$ increases.

Consequently the value of P for a given amount of compression, depends essentially on the vivacity of the explosion and on the mass of the piston.

31. MM. Sarrau and Veille were able, by means of a very ingenious apparatus, to obtain a series of curves showing the actual amount of compression as a function of the time, with various explosions, in various conditions, such as dust, fine grain, fragments of cake, and compressed blocks, and they thus ascertained—

(1) That, with ordinary gunpowder, the amount of compression is the same, whether the duration be $0''\cdot0015$ or $0''\cdot080$, that is to say, a variation of 1 to $53\frac{1}{3}$.

(2) That with explosives of a rapid nature, the compression *increases* as the duration *decreases*, so that its amount depends, not solely on the maximum pressure, but also on the law of its development.

(3) That ordinary gunpowder is the only explosive which, under ordinary conditions, produces compressions which may be considered as depending only on the maximum pressure.

32. With regard to the indications of the crusher gauge in a gun, there are two distinct conditions to be examined; 1st, when the crusher is behind the projectile; 2nd, when it is front of it.

33. In the first case, the pressure increases gradually from

zero to the maximum, and then decreases instead of remaining constant as in a close vessel.

34. After the maximum, the conditions are therefore different, but the action of the crusher will present no essential difference, provided the conditions of motion of the piston are such, that there shall be sensibly an equilibrium between the pressure and the force of resistance of the cylinder, at the time of the maximum, because the compression being then terminated, it is not subsequently altered. But the condition of this equilibum is, that the value of the ratio $\frac{\tau}{\tau_0}$ shall not be inferior to a limit, which, according to Sarrau and Veille, ranged between 2 and 3. From this it follows that this method of estimating the maximum pressure is justified, when the conditions are such that the duration of the compression from the moment of its origin to that of the maximum is two or three times greater than that of the same compression produced by a constant force, acting without initial velocity.

35. If, as is generally the case in France, the weight of the piston be about 30 grammes, the corresponding value of τ_0 is about $0''\cdot 00025$, consequently it will suffice if τ amounts to, or exceeds $0''\cdot 00050$ or $0''\cdot 00075$, and it may be admitted that this condition is generally satisfied in ordinary practice, from the ascertained value of the times which separate the origin of motion of the projectile in a gun, from the time of maximum pressure.*

36. Consequently the maximum pressure is sensibly equal to the "Force of Verification," provided this latter be determined by Sarrau and Veille's method.

If, however, the method of the Artillerie de la Marine be

* According to Sebert and Hugonet's experiments the times were found to be—

$0''\cdot 0010$ for a 10 cm. gun; projectile 12 kilo; charge 3·2 kilo; A_3S powder.

$\left.\begin{array}{l}0''\cdot 002\\ \text{to}\\ 0''\cdot 003\end{array}\right\}$ for a 24 cm. gun; projectile 144 kilo; charge 28 kilo; A_3S powder.

adopted the compressions are somewhat too great for a determinate force, and consequently the values of the force for a determinate compression are somewhat too small.

37. In the second case, when the crusher is in front of the projectile:—

Here the piston only receives the full pressure at the moment when the base of the projectile passes it. Thus the initial pressure is the maximum, applied suddenly, and therefore the motion is no longer the same as in the first case, where the initial pressure is zero. The compression is therefore no longer a simple relation to the corresponding "Force of Verification," so that the ordinary method of computation no longer applies.

38. If the crusher be placed approximately at the point of maximum pressure, the variation of pressure in the vicinity of such maximum is comparatively small, and if the time during which this variation is inconsiderable is of the same order of magnitude as τ_0 the compression will take place under the action of a sensibly constant force, and its value will be sensibly double of that which the same pressure would produce under the gradual action of the gases in the powder chambers on a gauge placed therein, behind the projectile.

39. This is the reason why the pressures, indicated by gauges, a little in advance of the first position of the projectile, are often found to be notably greater than those in the powder chamber. It is not that the latter are really less and the forces greater from some local action, as is often supposed, but it is simply due to the action of the apparatus itself, as is conclusively shown in the analysis of the problem given by Messrs. Sarrau and Veille.

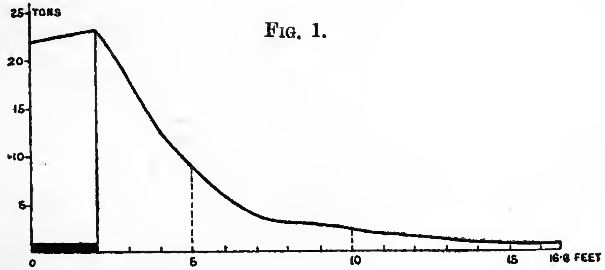
40. The study of Messrs. Sarrau and Veille's works shows that the interpretation of the results given by the crusher gauge is by no means so simple as is generally supposed, and that the mere fact of a cylinder being compressed to a certain amount is not necessarily an indication of the force which would produce the same compressions under the action of a testing machine.

41. It is for this reason that I have introduced the above remarks which might otherwise appear scarcely relevant to my subject, and if the conclusions to which my investigation of the action of the new powders lead, appear in some instances at variance with the indications of crusher gauges, it does not follow that they are equally at variance with the actual facts of the action of the powder.

42. The crusher gauge is no doubt a very valuable instrument, but it must be employed with a full knowledge of the peculiarities of its action, and although under these circumstances it may be thoroughly relied on as regards the maximum pressure in the chamber, it is not the same when used to determine the pressures *after the maximum*, whilst the projectile is passing along the chase to the muzzle.

43. To illustrate this I reproduce a diagram showing the results as deduced from experiments made by means of the crusher gauge, which is taken from a table given in the Woolwich 'Text-book on the Construction of Ordnance,' edition 1877.

Fig. 1.



44. Now the area of this curve taken from the base of the projectile in its original position up to the muzzle, multiplied by the area of the bore, represents the energy. This is found to be 9236 foot-tons. But the loss of energy in overcoming the passive resistances, friction, and expulsion of the gases, is certainly not less than 20 per cent., deducting which there remains 7391 foot-tons for the energy of the projectile.

The recorded velocity was 1409·3, and the weight of projectile 800 lbs., therefore the actual energy was 11,010 foot-tons, being 49 per cent. above that due to the recorded pressures. It is therefore evident that these pressures could not represent the actual pressures in the gun.

45. In a subsequent page I will refer in further illustration to some pressure curves contained in General Wardell's 'Handbook of Gunpowder and Guncotton,' printed by order of the Secretary of State for War in 1888. At present enough has been said to justify the statement that such pressure curves, deduced from the present interpretation of the indications of crusher gauges, do not correctly represent the real pressure in the chase, whilst the projectile is passing along it to the muzzle of the gun.

46. There are other methods, which may be termed dynamic, according to which may be determined the movement of the projectile as a function of the time, and thus, by the laws of mechanics, the pressures which produce such motion may be deduced.

47. Amongst them, probably the most successful are those made by means of the accelerograph and accelerometer of Colonel Sebert, but I have never been able to procure specimens of pressure curves actually obtained by these instruments. The instruments themselves are costly and very delicate in their construction, and, so far as I can learn, have not come into general use. At the same time, I think that they ought to give indications, much more reliable than those of the crusher, of the variations of pressure on the base of the projectile during its passage along the chase.

48. In practical gun construction this knowledge is of vital importance.

49. With the old powders, long experience has enabled gun-makers to give certain proportions to the chases of guns, but of late years indications have not been wanting to show that these proportions require modification for the slow-burning powders.

50. The new smokeless powders, however, are so different

in their constitution and in the results of their decomposition, that former experience can no longer be relied on, and it was chiefly with the object of throwing some light upon this most important subject that I undertook the investigation of which I now venture to give the result.

CHAPTER III.

51. In my treatise on 'Internal Ballistics,'* Chapter IV., I explained a method of constructing pressure curves, which I had frequently employed, based upon Noble and Abel's formula, and on the determination of the maximum pressure by M. Sarrau's formula.

52. I also showed how, by the use of Sarrau's formula for velocity, the pressure at any point of the projectile's course might be deduced, and pointed out by examples, that the curves thus obtained, and which represented the muzzle energy of the projectile, gave, after allowing for other resistances, satisfactory means of estimating the muzzle energy of the projectile.

53. But Noble and Abel's formula, as well as Sarrau's, referred to the ordinary powders, the products of combustion of which were not purely gaseous, but a mixture of gases with a very large proportion of inert matter in the form of a very finely divided liquid.

54. The new powders, on the contrary, are almost entirely converted into gases, and therefore, to that extent, the problem is more simple, and it occurred to me that it might be possible, by an extension of the method of curves above referred to, to arrive at results, which if not absolutely accurate, might yet be sufficiently so to be of practical utility.

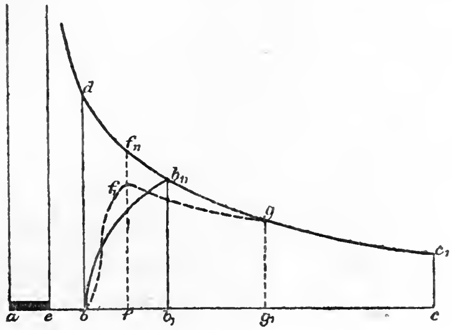
55. The method of curves depends partly on a known physical law and partly on an assumption.

56. Let *a e*, Fig. 2, represent the length of the charge in a cylindrical space whose diameter is that of the calibre of

* 'Internal Ballistics,' by J. A. Longridge, Spon, 1889.

the gun; $a\ b$, the "equivalent length" of the chamber, that is to say the length of a cylinder whose diameter is the same as the calibre of the gun and whose capacity is that of the chamber; $b\ c$, the travel of the projectile.

FIG. 2.



57. Then, if the projectile be immovable, and if $a\ e = a\ b$, the case is that of an explosive fired in a close vessel, and if the space be filled with ordinary powder at 27·73 inches to the pound, the pressure, according to Noble and Abel's experiments, will be 43 tons per square inch, which may be represented by the ordinate $b\ d$. If now the projectile be allowed to move, the pressures (supposing no loss by friction and other resistances) will be represented by the ordinates of a curve $d\ c_{ll}$, the equation to which is known, and the area of this curve $b\ d\ c_l\ c$, will represent the total energy per unit of area of the bore, from which the muzzle velocity is easily obtained.

58. But the projectile is not held back till all the charge is consumed. It begins to move as soon as the pressure behind it is sufficient to overcome the friction and passive resistances, and it moves forward under an increasing pressure up to a certain point at which the pressure is a maximum, and then continues its motion under the action of a decreasing pressure up to the muzzle.

59. The pressures acting on the projectile may therefore be represented by a curve such as $b\,b_{,,}\,c$, Fig. 2, and the area of this curve will represent the energy per unit of area of the bore.

To obtain this, the area of the curve, it is only required to know its equation, and the position and magnitude of the ordinate of maximum pressure.

Assuming that the whole of the charge is consumed at the position of maximum pressure $b_{,,}$ the equation to the curve $b_{,,}\,c_{,}$ is known. This is the first assumption.

60. The equation to the ascending branch of the curve $b\,b_{,,}$ is entirely unknown. It depends on the relation between the amount of gas evolved at any moment, and the space behind the projectile at the same moment of time.

61. Now the quantity of gas evolved depends partly on the varying pressures and partly on the form and density of the grains; consequently the analysis of the problem becomes very complicated, and is certainly beyond my grasp. I am consequently driven to make a second assumption, viz. that the area of the curve behind $b_{,}\,b_{,,}$ is the same as that of a quarter of an ellipse, the semi-axes of which are $b\,b_{,}$ and $b_{,}\,b_{,,}$.

62. Both these assumptions are disputable. As regards the second, the only justification I can give is that the results derived by the method of which it forms a part, agree very well with the actual results of experiment in a great variety of cases, the elements of which are very widely different.

63. As regards the first assumption, it is only an assumption in so far as it assumes that the whole charge is converted into gas at the time of maximum pressure, i. e. when the projectile is at the point $b_{,}$.

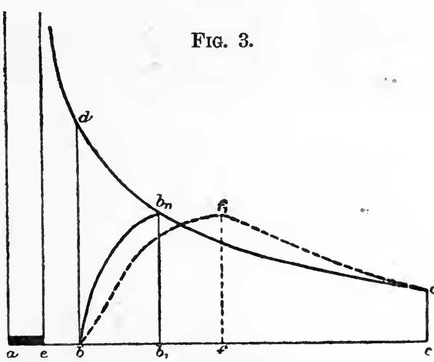
64. Of this I can give no proof. It may be asserted that the point of maximum pressure is at some distance behind the ordinate $b_{,,}\,b_{,}$ such as $f\,f_{,}$, and that at that point a portion only of the charge is burnt. If this be so the subsequent pressures will be represented by a curve such as

$f\,g$, which will fall into the curve $d\ b_{\prime\prime}\ c_{\prime}$ at some point g, and this curve $b\,f\,g$ must always fall below the curve $d\ b_{\prime\prime}\ g$, or else the point g must coincide with $b_{\prime\prime}$, in which case the pressure between f and $b_{\prime\prime}$ would be constant and equal to the maximum pressure.

Consequently, if the chase of the gun be calculated for the pressures of the curve $b_{\prime\prime}\ c_{\prime}$ it will always be sufficiently strong for the pressures, on the other hypothesis of the maximum falling behind $b_{\prime}\ b_{\prime\prime}$.

65. Again, the area of the curve $b\,f_{\prime}\ g\ c_{\prime}\ c$ must be equal to that of the curve $b\ b_{\prime\prime}\ c_{\prime}\ c$, otherwise there would be a deficiency of energy and a corresponding falling off of the muzzle velocity.

FIG. 3.



66. If it be said that the point of maximum pressure may be in front of the position $b_{\prime\prime}\ b$, it is easily shown that this is impossible. For let the dotted line Fig. 3 represent the pressures on this hypothesis and $f\,f_{\prime}$ the ordinate of maximum pressure. Then, even if the whole of the charge be consumed at this point, it is impossible that the pressure can be represented by an ordinate $f\,f_{\prime}$ greater than the corresponding ordinate of the curve $b\ d_{\prime\prime}\ c_{\prime}$, because this latter ordinate is that due to the volume of the whole of the products of the whole charge in the space corresponding to the projectile at $b_{\prime}$. In fact the ordinate corresponding to the entire combustion of the charge must be some point in the curve $d\ b_{\prime\prime}\ c_{\prime}$.

67. In like manner, the whole charge could not be consumed when the projectile is at any point $f_{,}$ (Fig. 2) behind the ordinate $b_{,}\ b_{,,}$, because the volume of gas in the space $b\,f$ would thus give a pressure $f_{,}\,f_{,,}$ greater than $f\,f_{,}$.

68. The result of this is that the pressures in the chase will never exceed those given by the curve $b\ b_{,,}\ c_{,}$, and may possibly fall below. Consequently, if the strength of the chase be calculated for the pressure of the curve $b_{,,}\ c_{,}$, it will always be safe under the actual pressures.

69. I proceed to show how the curve $b\ b_{,,}\ c_{,}$ is to be obtained.

In treating of these curves in my previous writings, I have proceeded on the assumption that the maximum pressure of powder in a close vessel (gravimetric density = 1) was 43 tons per square inch, and in calculating the ordinates I have adopted Noble and Abel's formula

$$p = p_0 \left(\frac{v_0\,(1 - a)}{v - a\,v_0}\right)^{1\cdot 0748}. \qquad (2)$$

70. These assumptions, although applicable to the old powders, cease to be so when the new smokeless powders are dealt with. The symbol a vanishes because the whole of the powder is gasified, and the index requires modification for the same reason.

Moreover the numerical value of $p_0 = 43$ cannot be invariable, and is in fact not so even with the old powders. It must depend upon the relation between a given weight of the powder and the space which is exactly filled by that weight, which relation is not invariable.

71. What is called gravimetric density = 1 (in France, densité de chargement) expresses the fact that 1 cubic decimetre of powder weighs 1 kilogramme, or 27·73 cubic inches 1 pound; but this depends upon the size of the grain. For instance, 1 cubic decimetre of the French powder designated F weighs 934 to 944 grammes, whilst of that designated A$\frac{30}{40}$ it weighs 1150 grammes, so that the so-called gravimetric densities are as ·934 to 1·150.

72. This difference is not taken into account by Noble and Abel, and it is of inconsiderable effect in dealing with the old powders, but with the new powders it must not be neglected.

73. The initial pressure in a close vessel of given magnitude is of course dependent on the ratio between the capacity of the vessel and the volume which the gas would occupy at atmospheric pressure.

Now, the volume of gas is proportionate to the weight of powder.

I have, therefore, in estimating the absolute pressure in a close vessel, taken the absolute volume of the charge, that is to say, the volume which it would occupy if it were a solid mass without interstices between the grains; in other words, the volume as obtained from its absolute specific gravity.

74. For instance, if the specific gravity of the powder be $1 \cdot 56$, the space occupied by 1 lb. would be $\frac{27 \cdot 75}{1 \cdot 56} = 17 \cdot 75$ cubic inches, and gravimetric density $= 1$ in this sense would be when $17 \cdot 75$ cubic inches space were allowed for each pound of the charge. If then a charge so spaced were converted into gas, the resulting pressure would be the "absolute" force of the powder.

75. This being so, and the gases being then allowed to expand doing work, the pressures at any point of the expansion would be denoted by the relation

$$p = p_0 \left(\frac{v_0}{v}\right)^\gamma \qquad (3)$$

where p_0 is the absolute pressure;

v_0 the original volume;

v the expanded volume;

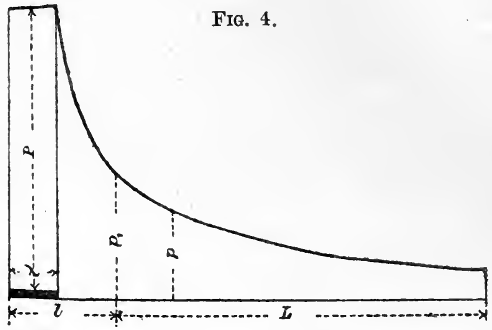
p the pressure at the expanded volume;

γ an index depending on the ratio of the specific heat at constant pressure to that at constant volume, and which, in the following investigations, I take at $1 \cdot 2$.*

* See Note A, Appendix.

76. Let, then (Fig. 4), λ denote the equivalent length of the charge considered solid, P the absolute pressure, the curved line calculated from the above relation (3) will represent the pressures of the expanding gases, and if there were no loss

FIG. 4.



of heat and no passive resistances, the area of this curve from the ordinate P to the end would be the energy of the projectile per unit of area of the bore, and any ordinate such as p, would represent the pressure at that part of the projectile's course.

77. In the case of a gun the projectile does not start from λ, but from a greater distance l, which is the equivalent length of the chamber as defined in § (56), but it is not retained at l until the pressure is p_1 (that corresponding to the distance l).

It moves on under an increasing pressure till it arrives at a certain distance along the chase, and then continues moving under a decreasing pressure to the end.

78. If, then, the position of the point of maximum pressure and its value be known, we may calculate the energy imparted from that point forward, and if the energy previously imparted be represented by an assumed function of the position and the magnitude of the maximum pressure, this, added to the other, will give the whole energy of the projectile, and from this the muzzle velocity may be obtained.

79. Consequently, if the absolute force of the powder and the maximum pressure be known, the velocity may be determined.

80. It must, however, be noted that the actual pressure on the base of the projectile at any moment, does not denote the pressure as given by the curve above described at the corresponding position of the projectile. That would be the case if the whole of the work done by the expanding gases were expended in giving motion to the projectile; but such is not the case, a portion is lost in heating the gun, another portion in the expulsion and friction of the gaseous products, and other minor effects.

81. Consequently, whatever be the percentage thus lost, a corresponding percentage must be added to the *observed* value of the maximum pressure, in order that the value so obtained shall really represent the value of the corresponding ordinate of the curve; and consequently, when we come to estimate the velocity of the projectile, a corresponding deduction must be made from the energy as represented by the area of the curve.

82. What this percentage should be, I am not in a position to say with certainty. In my treatise on 'Internal Ballistics' I went into the subject at some length and arrived at the conclusion, which agreed pretty nearly with the facts of experiment, that with ordinary gunpowder the actual energy imparted to the projectile did not exceed 68 to 75 per cent. of the total energy of the powder. A large proportion of the loss was due to the friction and expulsion of the products of combustion. The loss from this cause was very much greater than it would be with the new powders, partly because the absolute weight of charge was very much greater, and partly because there can be little doubt that the coefficient of friction of the products, less than half of which were really gaseous, must have been very much greater than that in the case of purely gaseous products such as arise from the new powders.

83. From these considerations I have assumed in the

following investigations that with the new powders the loss of energy does not exceed 10 per cent. of the whole, and that 90 per cent. is really imparted to the projectile.

84. Consequently, I have added one-ninth to the actual maximum pressure in making use of this as a factor which, in the following formulæ, is denoted by τ.

85. These formulæ, which are for the determination of the maximum pressure and the total energy of a given charge of powder, have been arrived at from the experiments made with Nobel's powder by Krupp, as recorded in the 'Revue d'Artillerie,' vol. xxxvi., 6th livraison of September 1889, containing the results of firing 468 rounds from 16 guns of calibres varying from 1·960 inch to 8·24 inches, and of various lengths up to 40 calibres, with seven powders varying in thickness of grain from 0″·0379 to 0″·393.

Formula for Maximum Pressure.

86. From a careful analysis of these experiments I have arrived at the following formula approximately representing the maximum pressure on the base of the projectile:

$$p = \frac{A\,W^{\frac{1}{2}}\,w^{\frac{3}{2}}}{\delta\, l\, c_{\prime}^{4}} \qquad (4)$$

in which

W = weight of projectile;

w = „ of charge;

δ = thickness of grain of powder;

l = equivalent length of chamber, that is to say, the length of a cylinder of the same diameter as the calibre of the gun, and of the same capacity as the actual chamber;

$c_{\prime}$ = the corrected diameter of the bore, that is to say, the diameter of a circle of the same area as the bore of the gun, augmented by the grooves of the rifling.

A = a constant for each kind of powder, depending on its composition and mode of manufacture.

Unities, pounds and inches.

87. In the investigation of this formula I have followed the analogy of Sarrau's formula for the maximum pressure on the base of the projectile, viz.

$$p = \frac{K a^2 \Delta (W w)^{\frac{1}{2}}}{c^2},$$

(See 'Internal Ballistics,' p. 88)

in which K is a constant; a, the "characteristic" of the powder equal to $\left(\frac{f\,a}{\tau}\right)^{\frac{1}{2}}$ where f is the "force" of powder, a a factor depending on the form of the grain, and τ the time of burning of a grain in free air.

Consequently,

$$a^2 = \frac{f\,a}{\tau}.$$

But the form of the grain in the Nobel powders used in the above experiments was the same, and so presumably was the composition, so that $f\,a$ is constant and may be included in A.

Also τ is directly proportional to the thickness, and may therefore be represented by δ.

88. In the next place, Δ, in Sarrau's formula, is in English measures $= \frac{27 \cdot 73\, w}{\cdot 7854\, c_{,}^2\, l}$, and including the numerical factor in the constant A, and replacing Δ in Sarrau's formula by $\frac{w}{l\, c_{,}^2}$, we get the expression given above.

$$p = \frac{A\, W^{\frac{1}{2}}\, w^{\frac{3}{2}}}{\delta\, l\, c_{,}^4}. \qquad (5)$$

89. From a careful analysis of the experiments, the value of A may be taken at about 300, applying which value the resulting values of p agree very fairly with the observed maximum pressures.*

90. The differences are, in fact, not greater than might reasonably be expected when there were differences in the

* See Note B, Appendix.

brands of powder, as well as probable inaccuracy of interpretation of the observations made with the pressure gauges, which in some cases were Rodman's, and in others crusher gauges.

91. Adopting this value of A, and adding, for reasons explained in § (84), one-ninth to the results, we get the value of Π as follows:—

$$\Pi = 300 \frac{W^{\frac{1}{2}} w^{\frac{3}{2}}}{\delta l c_{,}^{4}} \left(1 + \frac{1}{9}\right) \qquad (6)$$

92. It is to be borne in mind that the value of Π is not the actual pressure on the base of the projectile, but the pressure which would exist supposing that there were no loss by cooling or passive resistances. The ordinates of the pressure curves will therefore be in excess of the real pressures, and this excess will not be 10 per cent. uniformly throughout; but in estimating the effective energy the total deduction to be made will be 10 per cent.

Notwithstanding it will be best to consider that the real pressure to be resisted will be that denoted by Π, so that the calculated strength may always be in excess.

Formula for Total Energy.

93. In addition to the notation adopted in § (86),

Let λ = equivalent length of the charge considered as a solid block of powder occupying a cylinder whose diameter is $c_{,}$ at the spacing of 17·75 cubic inches to the pound of powder.

L = length of travel of projectile.

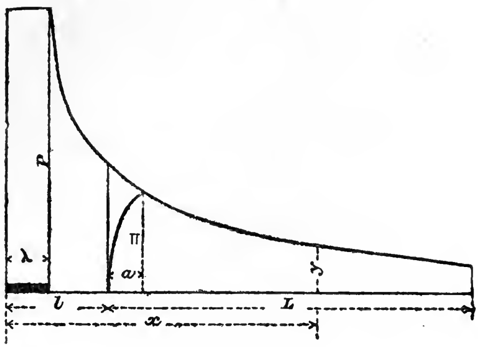
P = absolute pressure in tons per square inch.

Π = maximum pressure as defined by formula (6).

a = distance travelled at the moment of the maximum pressure.

y = pressure at any point x from the origin of motion.

Fig. 5.



Then (Fig. 5)

$$y = P\left(\frac{\lambda}{x}\right)^{\gamma},$$

and the total area of the curve up to the muzzle is

$$P\,\lambda^{\gamma}\int\frac{1}{x^{\gamma}}\,d\,x, \tag{7}$$

and the area of the portion in front of the maximum ordinate Π is

$$P\,\lambda^{\gamma}\int_{l+a}^{L+l} x^{-\gamma}\,d\,x. \tag{8}$$

But

$$\Pi = P\left(\frac{\lambda}{l+a}\right)^{\gamma},$$

and therefore

$$l+a = \left(\frac{P}{\Pi}\right)^{\frac{1}{\gamma}}\lambda. \tag{9}$$

The integral of (8) between the limits is

$$5\,P\frac{\lambda\,\gamma}{\gamma-1}\left\{\frac{1}{\left(\frac{P}{\Pi}\right)^{\frac{\gamma-1}{\gamma}}\lambda^{\gamma-1}} - \frac{1}{(L+l)^{\gamma-1}}\right\}$$

and making $\gamma = 1 \cdot 2$, this becomes

$$5\,P\,\lambda^{1 \cdot 2}\left\{\frac{1}{\left(\frac{P}{\Pi}\right)^{\cdot 166}\lambda^{\cdot 2}} - \frac{1}{(L+l)^{\cdot 2}}\right\} \tag{10}$$

the area in front of the ordinate of maximum pressure.

94. As was stated above, § (60), the equation of the curve behind the ordinate of maximum pressure is unknown, and is assumed to be such that the area bounded by it and the ordinate π is equal to that of the fourth part of the area of an ellipse, the semi-axes of which are Π and a, or $\cdot 7854\ \Pi\ a$. Substituting for a its value from (9) we get the area

$$\cdot 7854\,\Pi\left\{\left(\frac{P}{\Pi}\right)^{\cdot 833}\lambda - l\right\}. \tag{11}$$

95. Adding together (10) and (11), and multiplying by $\cdot 7854\ c_{\prime}^2$, the area of the bore, we get the total energy,

$$E = \cdot 7854\,c_{\prime}^2\left[5\,P\,\lambda^{1 \cdot 2}\left\{\frac{1}{\left(\frac{P}{\Pi}\right)^{\cdot 166}\lambda^{\cdot 2}} - \frac{1}{(L+l)^{\cdot 2}}\right\}\right.$$
$$\left. + \cdot 7854\,\Pi\left\{\left(\frac{P}{\Pi}\right)^{\cdot 833}\lambda - l\right\}\right], \tag{12}$$

which is the total energy in inch-tons. Dividing this by 12 gives the energy in foot-tons. Deducting one-tenth for loss by cooling and other resistances we get the energy of the projectile, and if W be taken in pounds, we get finally

$$\frac{\cdot 9\,E}{12} = \frac{V^2\,W}{2\,g \times 2240}, \tag{13}$$

from which the muzzle velocity of the projectile V is obtained.

The expression (12) may be put into a simpler form by making $l = n\,\lambda$ and $L = m\,\lambda$, and observing that $\lambda = \dfrac{17 \cdot 75\,w}{\cdot 7854\,c_{\prime}^2}$ we get finally

$$E = 17 \cdot 75\,w\left[5\,P\left\{\left(\frac{\Pi}{P}\right)^{\cdot 166} - \frac{1}{(n+m)^{\cdot 2}}\right\}\right.$$
$$\left. + \cdot 7854\,\Pi\left\{\left(\frac{P}{\Pi}\right)^{\cdot 833} - n\right\}\right] \tag{14}$$

and the energy per lb. of powder,

$$\frac{E}{w} = 17 \cdot 75 \left[5\,P \left\{ \left(\frac{\Pi}{P}\right)^{\cdot 166} - \frac{1}{(n+m)^{\cdot 2}} \right\} \right.$$

$$\left. + \cdot 7854\,\Pi \left\{ \left(\frac{P}{\Pi}\right)^{\cdot 833} - n \right\} \right]. \qquad (15)$$

96. To apply this formula it is necessary to determine the value of P for each kind of powder. This is done by obtaining the energy of the projectile from the average of a number of rounds, and then solving (12) for P. This gives the following relation :

$$1 \cdot 157\,\Pi^{\cdot 166} \left(\frac{L+l}{\lambda}\right)^{\cdot 2} P^{\cdot 833} - P = \left\{\frac{E}{a_{,}} + \cdot 7854\,\Pi\,l\right\} \frac{(L+l)^{\cdot 2}}{5\,\lambda^{1 \cdot 2}}; \quad (16)$$

where $a_{,}$ is the area of the bore, from which P may be found by approximation.

97. In order to obtain the correct value of P from (16) a series of careful experiments are necessary with the same powder, so as to obtain the muzzle velocity and maximum pressure with a given charge.

The experiments which are at my disposal being made with different brands of powder are consequently insufficient, but from a careful examination of them I am disposed to fix provisionally the value of P at 175 tons per square inch for the Nobel powder, which is therefore the value I have adopted in the verification given hereafter.

98. This is the value of P supposing the powder to be in a solid block spaced at 17·75 inches to the pound. If, however, it were in the form of grains and occupied 27·75 inches to the pound the pressure would be $175 \left(\frac{17 \cdot 71}{27 \cdot 73}\right)^{1 \cdot 2}$ $= 102 \cdot 5$ tons per square inch.

99. From Sarrau and Veille's experiments with the crusher gauge, with gun-cotton, nitro-cellulose, and nitro-glycerine in the form of dynamite, the pressure in a close vessel of

these explosives, supposing them spaced at 27·73 inches to the pound, would be

Nitro-cellulose ..	..	113·6 tons per square inch.
Gun-cotton ..	..	114·2 ,, ,,
Dynamite	..	75·0 ,, ,,
Average about	..	101·0 ,, ,,

Now these are analogous compounds to Nobel's powder, and the average result is very nearly that just arrived at by taking P = 175 as found above. It may therefore be inferred that the formulæ as obtained from Krupp's experiments represent approximately the fact.

Verification of Formula.

100. It may be well to give an example of the application of the above formula by way of comparison with the actual results. For this purpose I take the 1·9681 inch gun of 40 calibres, of which the following are the ballistic elements:—

Corrected Calibre.	Capacity of Chamber.	Travel of Projectile.	Weight of Projectile.	Weight of Charge.	Thickness of Grain.
c_i	C	L	W	w	δ
2·0035	53·68	60″	3·85	0·66	·079

101. To find c_i:

Area of 1·9685 inches ..	..	3·045 square inches.	
Add grooves	..	·105 ,,	
Total area ..	..	3·150 ,,	$= (a_i)$.

$$\text{Therefore } c_i = \sqrt{\frac{3 \cdot 150}{\cdot 7854}} = 2 \cdot 003 \text{ inches.}$$

102. To find l and λ:

$$l = \frac{C}{a_i} = \frac{53 \cdot 68}{3 \cdot 15} = 17 \cdot 04 \text{ inches}$$

and

$$\lambda = \frac{w \times 17 \cdot 75}{a_i} = \frac{\cdot 66 \times 17 \cdot 75}{3 \cdot 15} = 3 \cdot 721 \text{ inches.}$$

103. To find Π:

By (6) (§ 91),

$$\pi = 300\,\frac{W^{\frac{1}{2}}\,w^{\frac{3}{2}}}{\delta\, l\, c_{\prime}^{4}}\,(1 + \tfrac{1}{9}).$$

Log 300	=	2·47712
„ $3·85^{\frac{1}{2}}$	=	·29273
„ $·66^{\frac{3}{2}}$	=	$\bar{1}$·72971
		2·49916
	Deduct	1·33757

Log ·079	=	− 2·89763
„ 17·04	=	1·23150
„ $2·004^4$	=	1·20844
		1·33757

Log p = 1·16159 = Log 14·51 = p

Add Log 1·111 ·04571

Log Π 1·20730 = Log 16·12 = Π.

The observed value of p was 14·42, which agrees very nearly with the calculated value of p.

104. To find E the total energy:

By (12) (§ 95),

$$E = ·7854\,c_{\prime}^{2}\left[5\,P\,\lambda^{·2}\left\{\frac{1}{\left(\frac{P}{\Pi}\right)^{·166}\lambda^{·2}} - \frac{1}{(L + l)^{·2}}\right\} + ·7854\,\Pi\left\{\left(\frac{P}{\Pi}\right)^{·833}\lambda - l\right\}\right].$$

1*st Term.*

Log 5 P	= 2·94201
„ $\lambda^{1·2}$	= ·68474
	3·62675
Add Log ·0973	− 2·98811
	2·61486
= Log of	412

Log P	= 2·24304
„ Π	= 1·20730
„ $\frac{P}{\Pi}$	= 1·03574
„ $\left(\frac{P}{\Pi}\right)^{·166}$	= ·17262
„ $\lambda^{·2}$	= ·11412
„ $\left(\frac{P}{\Pi}\right)^{·166}\lambda^{·2}$	= ·28674

Log of Recipl. − $\bar{1}$·71326 = Log ·5167

Deduct ·4194

·0973

Log $77·04^{·2}$ = ·37734

„ Recipl. − $\bar{1}$·62266

= Log ·4194

2nd Term.

$$\text{Log} \left(\frac{P}{\Pi}\right)^{\cdot 833} = \cdot 86287$$

$$\text{,,} \quad \lambda \quad = \cdot 57062$$

$$1 \cdot 43349 = \text{Log } 27 \cdot 13$$

$$\text{Deduct } l = 17 \cdot 04$$

$$10 \cdot 09$$

$$\text{Log } 10 \cdot 09 = 1 \cdot 00389$$

$$\text{,,} \quad \cdot 7854 = -1 \cdot 89509$$

$$\text{,,} \quad \Pi = 1 \cdot 20730$$

$$1 \cdot 10628 = \text{Log } 127 \cdot 73$$

Value of 1st term	412
,, 2nd ,,	127·93
	539·73

$$\text{Log } 539 \cdot 73 = 2 \cdot 73217$$

$$\text{Add Log } \cdot 7854 \,.\, c_{\prime}^{2} = \cdot 49835$$

$$3 \cdot 23052$$

$$\text{Deduct Log } 12 \quad 1 \cdot 07918$$

$$2 \cdot 15134 = \text{Log } 141 \cdot 7 \text{ foot-tons.}$$

Total energy	= 141·7 foot-tons.
Deduct one-tenth	14·17 ,,
Energy of Projectile	127·53 foot-tons = E_1.

105. To find muzzle velocity :

$$MV = \sqrt{\frac{E_1 \times 2\,g \times 2240}{W}}$$

$$= \sqrt{\frac{127 \cdot 53 \times 64 \cdot 4 \times 2240}{3 \cdot 85}} = 2186 \text{ feet per second.}$$

106. The observed velocity at 164 feet from muzzle was 2135 f.s., to which must be added the loss of velocity in passing through 164 feet, which according to Bashforth's

formula would be 53 feet per second, making the muzzle velocity 2188 feet per second, very nearly the same as the calculated velocity. The energy per pound of powder is

$$\frac{127 \cdot 53}{\cdot 66} = 193 \cdot 1 \text{ foot-tons.}$$

107. The accordance between the results of calculation and observation in this case is certainly greater than could be expected under the circumstances; but the following table (I.) shows that in general there is such a degree of approximation as to justify the belief that the formula is correct in principle.

It will be seen that the guns vary from $1'' \cdot 9605$ to $8'' \cdot 24$ in calibre, and from 13 to 40 calibres in length, that the charges of powder vary from $0 \cdot 297$ to $48 \cdot 5$ lbs., and the size of grains from $0'' \cdot 0395$ to $0'' \cdot 393$, whilst the weight of projectile varies from $3 \cdot 85$ to $308 \cdot 7$ lbs.; so that the ballistic elements vary through a very considerable range.

It will be observed that the calculated results are generally a little too high, which points to an overestimate of P, or an underestimate of the losses; but the differences are not important in any case.

108. These examples, which are taken quite at random from the experiments, show that under very varying circumstances the formula for energy gives results sufficiently in accordance with the observed results to justify the assumptions which have been made.

The differences are not greater than may arise from the facts that the brands of powder were different, and indeed there is ample evidence of this in the table of experiments themselves.

For instance, taking the average of 21 rounds fired from the $2 \cdot 952$ gun on 17th February, 1890, with powder of September 1889, and comparing the pressures on the same day in the same gun with powder of February 1890, it will be found that the coefficient A in formula (6) is $6\frac{3}{4}$ per cent. higher with the powder of February 1890, than with that of

TABLE I.—TABLE OF VERIFICATION.

	Calibre.	Length in Calibres.	No. of Rounds.	Size of grain δ.	Projectile.	Charge.	Muzzle Velocity.		Maximum Pressure.		
							Calculated.	Observed.	Calculated. Tons per sq. in. Π	p	Observed.
	inches.				lbs.	lbs.	ft. per sec.	ft. per sec.			tons per sq. in.
1	1·968	40	9	·079	3·85	0·66	2186	2187	16·13	14·57	14·42
2	2·362	40	2	·118	6·60	1·12	2087	2058	14·00	12·60	12·25
3	2·952	13	9	·0395	8·60	0·297	997	979	11·55	10·40	9·07
4	2·952	25	2	·118	13·20	1·276	1614	1561	12·43	11·19	11·89
5	2·952	28	10	·157	15·06	1·543	1779	1800	15·47	13·92	13·80
6	3·43	30	10	·118	15·00	1·98	2056	1999	13·90	12·51	12·57
7	3·96	35	1	·197	35·20	4·30	1889	1856	13·50	12·25	12·01
8	4·74	24	2	·157	35·20	4·96	2096	1990	15·50	13·96	14·37
9	5·875	30	1	·295	88·00	6·615	1314	1217	5·76	5·19	6·60
10	5·875	30	1	·295	88·00	9·921	1736	1645	10·57	9·53	9·92
11	5·875	30	10	·295	88·00	12·17	1992	1920	14·30	12·87	12·10
12	5·875	30	1	·393	113·0	18·74	1926	1932	12·85	11·86	12·97
13	8·24	35	1	·393	238·0	36·43	1823	1837	8·98	8·08	8·01
	8·24	35	1	·393	309·0	48·50	2005	2005	15·70	14·30	14·90

September 1889. It is therefore not surprising that differences should be found of the same order of magnitude in the above table of Verification.

Cordite and French B.N.

109. The information which has been made public respecting these powders is very scanty, so that the few remarks which I am able to make regarding them must be taken with all reserve.

110. To begin with Cordite. The results of trials with the 12-pounder 3-inch gun, and with the 6-inch Q.F. gun, have been published, as well as certain of the ballistic elements, such as weight of charge and projectile, length of gun, muzzle velocity, and, in the first instance, maximum pressure.

111. Submitting these data and results to calculation, it would appear that the ultimate force of Cordite is about 160·7 tons per square inch.

112. Assuming a similar formula for the maximum pressure as was arrived at for the Nobel powder, we get

$$p = A_{,} \frac{W^{\frac{1}{2}} w^{\frac{3}{2}}}{l c_{,}^{4}}, \qquad (17)$$

in which $A_{,}$ takes the place of $\frac{A}{\delta}$ in formula (6)—a substitution which I am obliged to make through ignorance of the dimensions of the Cordite.

From the experiments with the 12-pounder 3-inch gun, the value $A_{,}$ is found to be 2935; therefore

$$\Pi = 2935 \frac{W^{\frac{1}{2}} w^{\frac{3}{2}}}{l c_{,}^{4}} (1 + \tfrac{1}{9});$$

and making use of this value and the above value of P in (12), and calculating with the given ballistic data, we get the following table of results :—

TABLE II.

Rounds.	Energy per lb. of powder.	Muzzle Velocity.		Pressures.		
		Calculated.	Observed.	Π	p	Observed.
	foot-tons.	f. s.	f. s.			
5	280	1740	1751	18·59	16·73	16·8
10 and 11	242	1673	1709	15·17	13·66	14·4
13 and 16	271	1654	1697	18·69	16·82	16·9

113. Again, for the 6-inch Q.F. gun, fired with 19½ lbs. Cordite and 100-lb. projectile,

The value of $A_{,}$ is found to be 1534, and

$$\Pi = 1534 \frac{W^{\frac{1}{2}} w^{\frac{3}{2}}}{l\, c_{,}^{4}} .$$

Making use of which and the value of $P = 160 \cdot 7$, the calculation by (12) gives muzzle energy 4905 foot-tons, which gives muzzle velocity 2677 feet per second, which was within a few feet of the observed velocity.

The energy per lb. of powder in this case was

$$\frac{4905}{19 \cdot 5} = 251 \cdot 6 \text{ foot-tons.}$$

114. The pressure p, as calculated from the formula, is nearly 27 tons per square inch, which is much greater than is usually allowed at Woolwich. The observed pressure was not published, but the high muzzle velocity indicates a corresponding high pressure.

B.N. POWDER.

115. The data in my possession regarding the new French powder are a little more extensive than those regarding Cordite.

They consist of the results of firing—

(A) Six rounds of	B.N. Lot 1 from	3·937 inch gun.
(B) Five ,,	B.N. Lot 3 ,,	3·937 ,,
(C) Nine ,,	B.N. ,,	5·90 ,,
(D) Six ,,	P.B.N. ,,	10·92 ,,

116. From these I have deduced the following formula for the maximum pressure:—

$$\text{Group A} \quad .. \quad .. \quad p = 935\,\frac{W^{\frac{1}{2}}\,w^{\frac{3}{2}}}{l\,c_{,}^{4}}$$

$$\text{,, B} \quad .. \quad .. \quad p = 836\,\frac{W^{\frac{1}{2}}\,w^{\frac{3}{2}}}{l\,c_{,}^{4}}$$

$$\text{,, C} \quad .. \quad .. \quad p = 530\,\frac{W^{\frac{1}{2}}\,w^{\frac{3}{2}}}{l\,c_{,}^{4}}$$

$$\text{,, D} \quad .. \quad .. \quad p = 321\,\frac{W^{\frac{1}{2}}\,w^{\frac{3}{2}}}{l\,c_{,}^{4}}$$

The variation in the numerical coefficient is probably due partly to a difference in the brand of powder, and partly to the difference in the form and size of the grain, respecting both of which no details are published.

117. Employing the above formula for the pressure in formula (16), the following are the average results for the maximum force:—

			Tons per sq. inch.
For Group A ..	.. 3·937 inch gun	..	P = 108 3
,, B ..	.. ,, ,,	.. ..	P = 90
,, C ..	.. 5·9 ,,	.. ..	P = 133
,, D ..	.. 10·92 ,,	.. ..	P = 102

118. There thus appears to be considerable variation in the strength of these brands of powder, even in the same gun.

For instance, in groups A and B, the difference is as 12 to 10, and this is confirmed by a comparison of the energy imparted to the projectile for each lb. of powder. Taking for instance the last two rounds of group A, and comparing them with the first two of group B, in which the weight of charge was approximately the same, and with the same weight of projectile, the energy per lb. of powder was 159·5 foot-tons in the first case, and 125 foot-tons in the second, or as 12 to 9·38, thus confirming the results in § (117).

Comparison of the Three Powders.

119. The results above given may now be compared as regards ultimate force and energy per lb. of powder.

I.—Ultimate Force = P.

	Tons per sq. inch.
Nobel powder, average	175·0
Cordite „	160·7
B.N. Lot 1 in 3·937 inch gun ..	108·3
„ Lot 3 in 3·937 „ ..	90·0
„ in 5·9 „ ..	133·0
P.B.N. in 10·92 „ ..	102·0

120. II.—Energy of Projectile per Lb. of Powder.

Powder.	Calibre.	Length in calibres.	Projectile.	Charge.	Energy per lb. of powder.
			lbs.	lbs.	
Nobel	5·9	35	113	18·60	195 foot-tons
Cordite	6·0	40	100	19·50	255 „
B.N.	5·9	36	94	33·	140 „

The low effect of the B.N. powder is chiefly due to the greatly increased charge, compared with the weight of projectile.

121. I will therefore now give the results of calculations from the above formula under exactly similar conditions of firing, viz.:—

Weight of charge	19·5 lbs.
Weight of projectile	100 lbs.
Travel of projectile	216·9 inches.
Equivalent length of chamber	37·9 inches.
Corrected calibre including grooves ($c_{,}$)	6·061 inches.

Making use in each case of the formula given above,

The following table represents the results :—

Name of Powder.	P Ultimate Force.	p Maximum Pressure on Projectile.	MV Muzzle Velocity.	E Energy of Projectile.	$\frac{E}{w}$ Energy per lb. of Powder.
	tons per sq. in.	tons per sq. in.	feet per second.	foot-tons.	foot-tons.
Nobel	175	12·99	2433	4105	210·5
Cordite	160·9	26·10	2677	4967	254·7
B.N.	133	9·02	2068	2965	152·0

122. It may appear at first sight strange that the useful effect of the Cordite is greater than that of the Nobel powder, whilst the absolute force of the powder is less. The reason of this is that the Cordite is worked at a much higher maximum pressure; the advantage of which will be fully apparent in a subsequent part of this treatise.

CHAPTER IV.

123. These results, I must again repeat, are not to be taken without reserve. The formulæ by which they are obtained depend in some degree upon assumptions which I have no means of proving and which it may be well again to refer to.

124. 1st. I have assumed that the absolute specific gravity of the three powders is the same, say about 1·65, or 17·75 cubic inches to the pound of powder, or what amounts to the same thing, that in each case the absolute force of the powder is calculated for one and the same density of manufacture, and the value of λ in the formula is calculated for this density.

2nd. That the effective pressure on the projectile is 10 per cent. less than the pressure calculated on the hypothesis that there is no loss by cooling and passive resistances. This assumption may be erroneous, either in excess or defect, but it does not affect the relative values of the results.

3rd. That the energy of the projectile may be represented by the area of a curve such as has been described, one part of which is assumed to be equal to the fourth part of an ellipse of which the semi-axes are the maximum pressure ordinate and the distance moved by the projectile at the position of that ordinate, and the other part is the area of a curve of the form

$$p = \mathrm{P}\left(\frac{\lambda}{l + x}\right)^{\gamma}$$

(in which P is the absolute force of the powder, and γ an index $= 1 \cdot 2$) taken in front of the position of maximum pressure.

This assumption implies that after the projectile has reached a position where the pressure is represented by the corresponding ordinate of the curve, the whole of the charge has been converted into gaseous products.

125. It is very often believed that the pressure curve is of a very different form from that which represents my assumption, and that owing to the continued combustion of the charge during the passage of the projectile an approach to a mean uniform pressure is obtained.

126. In a preceding section (§ 45) I have alluded to certain pressure curves given by Maj.-Gen. Wardell, R.A., in his 'Handbook of Gunpowder and Gun-cotton,' 1888.

No reference to these curves is given in the text, but they are contained in a plate, inserted at p. 67, bearing the title, "Pressure Curves for Black and Brown Powder."

They are four in number, and purport to be the pressure curves under the following conditions:—

R.L.G. Powder	in 10-inch	R M.L.	gun.
P^2	,,	,, 12·5 ,,	,,	,,
Black Prismatic	,,	9·2 ,,	R.B.L.	,,
Brown Prismatic	,,	9·2 ,,	,,	,,

127. It is to the two latter curves that I will confine my attention, because they refer to the same gun, and I now reproduce them (Figs. 6 and 7), altering the scale for the sake of convenience.

128. Taking first the diagram for 140 lbs. Black Prismatic, Fig. 6. The full line is Gen. Wardell's curve, and the dotted lines the curves according to Noble and Abel's formula.

The respective areas are

Wardell's curve	142·60
Noble and Abel	154·35

which multiplied by 66·47, the area of the base, gives the energy

Wardell's curve	9479 foot-tons.
Noble and Abel	10258 ,,

129. For black prismatic powder, I have generally found that the useful effect on the projectile varies from 75 to 80 per cent. of the whole energy. Assuming this to be 78

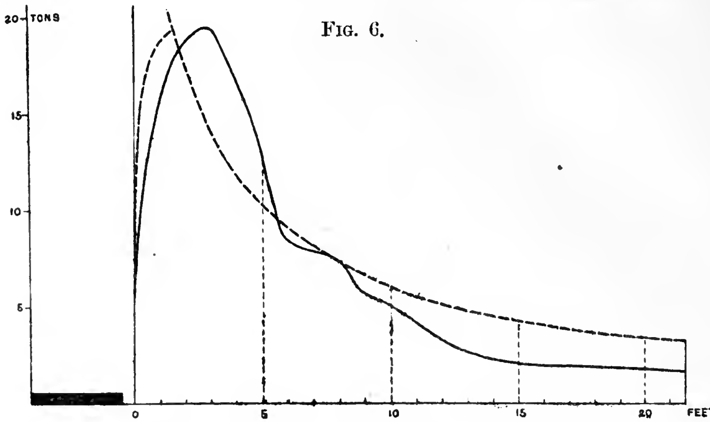


FIG. 6.

per cent., the velocities as derived from the above energies will be

By Wardell's curve	.. ..	1680 feet per second.
,, Noble and Abel's curve	..	1723 ,, ,,

The observed velocity was 1708 feet per second.

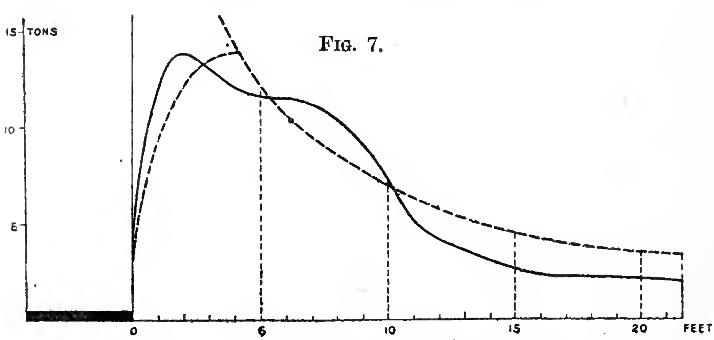


FIG. 7.

130. For the curve, Fig. 7, for 160 lbs. Brown Prismatic the respective areas are

By Wardell's curve	.. .. ..	146·3
,, Noble and Abel's curve	.. ..	150·35

which multiplied by 66·47, the area of the base, gives the energy

By Wardell's curve ..	..	9725 foot-tons.
„ Noble and Abel's ..	..	9992 „ „

The useful effect with brown powder I have found to be about 90 per cent. of the curve energy, and taking this, the deduced velocities will be

By Wardell's curve ..	..	1835 feet per second.
„ Noble and Abel's ..	..	1865 „ „
The observed velocity	..	1798 „ „

131. It thus appears that the velocities with both powders, as deduced from Noble and Abel's curve, are nearly the same as those from Wardell's curves, whilst, as compared with the observed velocities, they are nearly the same with the black powder, but about $2\frac{1}{2}$ per cent. greater with the brown powder.

132. Practically, then, the two sets of curves give the same result, and so far there is nothing to be said against Wardell's curves.

133. If, however, the curves be examined from another point of view, it will appear difficult to believe that Wardell's curves can really represent the pressures.

134. Taking first the curve for the black powder. When the projectile has moved 4 feet, which corresponds to two expansions, the pressure by Wardell's curve is about 17·0 tons per square inch, and, assuming the whole of the powder to be burnt, this corresponds to a pressure of 11·80 tons per square inch by Noble and Abel's formula.

135. Again, when the projectile has moved $13\frac{3}{4}$ feet, corresponding to four expansions, the pressure by Wardell's curve is about $2\frac{1}{2}$ tons per square inch, whilst by Noble and Abel's formula it should be 4·70 tons per square inch.

136. Again, for the brown powder, when the projectile has arrived at 6·4 feet, corresponding to 2·50 expansions, the pressures are

By Wardell's curve ..	..	11·4 tons per sq. in.
„ Noble and Abel's curve ..		8·57 „ „

And when the projectile has moved 15 feet the pressures are

By Wardell's curve	2·73 tons per sq. in.
„ Noble and Abel's curve ..	4·60 „ „ „

137. It is evident that these differences are inconsistent with any simply mechanical law connecting pressure with expansion.

138. If Wardell's curves be correct, the rate of combustion of the powder must be exceedingly erratic.

With the black powder, the pressure falls from $19\frac{1}{2}$ tons to 8 tons, whilst the projectile moves $3\frac{1}{2}$ feet (i. e. from $2\frac{1}{2}$ to 6 feet). It then remains nearly stationary whilst the projectile moves 2 feet (from 6 to 8 feet), and then falls from 8 to $2\frac{1}{2}$ tons whilst the projectile moves $5\frac{1}{2}$ feet (from 8 to $13\frac{1}{2}$ feet).

139. With the brown powder, the pressure falls from 14 tons to 12 tons whilst the projectile moves 2 feet (2 to 4 feet), then falls about 1 ton whilst the projectile moves 4 feet (from 4 to 8 feet), and again falls from 11 tons to $2\frac{3}{4}$ tons whilst the projectile moves 7 feet (from 8 feet to 15 feet).

140. Now the pressure is a function of the evolution of gas, and an inverse function of the space, and it seems incredible that any mathematical function can represent such anomalous variations of pressure as are shown in General Wardell's curves.

141. It is of course possible *to imagine* the possibility of these variations if the question be considered from the point of view of chemical energy. It is possible to conceive developments of energy, arising from such phenomena as Dissociation and other laws of what is called in France "Mécanique Chimique," but if such laws give rise to such variations as are shown by Wardell's curves, the determination of the pressures in a gun would appear to be a hopeless endeavour, and gun construction, so far as regards the strength of the chase, to be hardly within the range of practical science.*

142. On the other hand, the formulæ which I have sug-

* See Note C, Appendix.

gested rest upon a rational basis, and give results which are in satisfactory accordance with those of experiment.

143. As an instance of this I will now give an example of their application, and for this purpose will take the use of Cordite in the 3-inch 12-pounder gun already referred to in § (110).

144. *Application of Formula to 3-inch gun.*

Rounds 13 and 14.

BALLISTIC ELEMENTS.

$c_{\prime}$	λ	l	L	W	w	P
3·026	2·16	6·05	75·	12·5	·875	160·7

To find maximum pressure on base of projectile.

$$p = \frac{2935\, W^{\frac{1}{2}} w^{\frac{3}{2}}}{l\, c_{\prime}^{4}} = 16\cdot82 \text{ tons per sq. inch.}$$

$$\text{Add } \tfrac{1}{9} \quad 1\cdot98$$

$$\text{Gives} \quad \Pi = 18\cdot80 \quad ,, \quad ,, \quad ,,$$

Making use of which in formula (12), we get

$$E = 282\cdot2 \text{ foot-tons}$$

$$\text{Deduct } \tfrac{1}{10} \quad 28\cdot2$$

$$\text{Energy of projectile } 254\cdot0 \quad ,,$$

$$\text{and Muzzle velocity} = \sqrt{\frac{254 \times 2g}{12\cdot5 \times 2240}} = 1712 \text{ feet per second.}$$

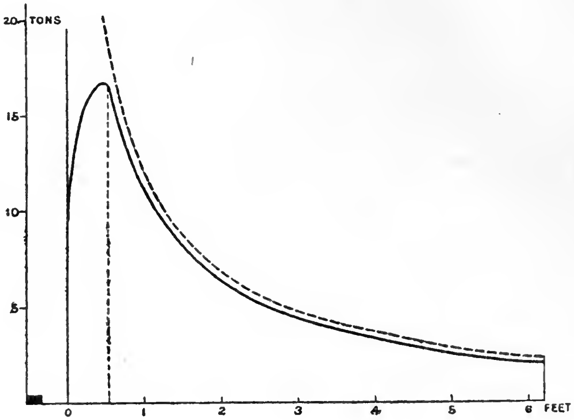
145. These results agree very well with the experimental result as appears below :—

Calculated velocity	..	..	1712 feet per second.
Observed ,,	..	..	1697 ,, ,,
Calculated pressure	..	..	16·82 tons per sq. inch.
Observed ,,	..	..	16·90 ,, ,,

146. To construct the pressure curve we have the equation

$\Pi = 160 \cdot 7 \left(\frac{\lambda}{l + x}\right)^{1 \cdot 2}$ where $\lambda = 2 \cdot 16$, $l = 6 \cdot 05$, and x is any distance from the origin of motion, and p the pressure on the projectile $= \frac{9}{10} \Pi$.

Fig. 8.



147. In this way the curve Fig. 8 has been constructed, the dotted lines showing the values of Π, and the full lines those of p, the effective pressure on the base of the projectile. The area of the full line multiplied by the area of the base gives the energy of the projectile = 254 foot-tons, corresponding to a velocity of 1712 feet per second, which is only 15 feet per second above the observed velocity. Consequently, the curve really represents the actual energy of the gases.

148. How far it agrees with the results given by the crusher gauges I am not in a position to say, but the comparison can easily be made by those who have the actual results in their possession.

149. In the comparison between the three powders given in §§ (119) and the following, it is not intended that the figures given with respect to the Cordite and French powders shall be accepted as actual facts. As regards the Nobel powder, they probably approach nearly to the truth, whilst

in the case of the other two powders they are little more than suggestive. It is very possible that the absolute specific gravity of these two powders may be greater or less than 1·56, which would of course involve a corresponding variation in the value of P, the absolute force of the powder.

150. Again, the formula for the maximum pressure is not sufficiently explicit for general use. It does not contain explicitly either the dimensions or the form of grain, so that it is only applicable to the particular guns which in each case were employed, and moreover, it is quite possible that there may be a variation in the index of w, that is to say that this index may be different with different powders. I could only use such results as were in my possession for the Cordite and the French powders, whilst with the Nobel powder I had a large number of experiments, in which the ballistic elements varied to a very considerable extent; but the results arrived at with this latter powder are, I think, such as to justify the method adopted, and to lead to the belief that with a sufficiency of data this method may be equally applied to the other powders, and that by its application to the data furnished by carefully conducted experiments, formulæ may be constructed, for each description of powder, which will give the solution of the ballistic problems such as the muzzle velocity, the maximum pressure, and the rate of variation of the pressure as the projectile passes along to the muzzle of the gun.

151. This last is perhaps the most important of the three as regards gun construction, and it is certainly the one about which least is known.

152. I am quite free to admit that I can give no actual proof that my formula really represents the actual variation of pressure.

In fact, this will probably be strenuously denied by those whose notions about slow-burning powder have convinced them that the form of the pressure curve mainly depends upon the continuance of the combustion of the charge

during nearly the whole time of the passage of the projectile along the chase.

153. But what does this involve, and on what evidence does it rest? I think mainly on the evidence of such curves as those given above (§ § 43 and 127).

If these curves really represent the pressures, we must conclude that for each kind of powder there must be a differently proportioned chase. For the Black Prismatic the greatest thickness of the chase should be about 3 feet in front of the powder chamber. At the end of the next 3 feet it would require to be less than half the strength, and continue so for a length of about 2½ feet. Then, for a length of about 5½ feet the strength would decrease to about one-fourth of the original strength, and continue so to the muzzle of the gun.

154. It is further obvious that if this curve be correct the last 4 feet of the chase is of very little use, since the increase of energy due to it is only 403 foot-tons, corresponding to an increase of 47 feet per second in velocity.

155. Moreover a gun constructed for this powder would be altogether unsuited for the charge of brown powder shown in the other curve. For instance, at 7 feet from the chamber, the black powder gun would have to resist a strain of 6¾ tons per square inch, whereas at the corresponding point in the brown powder gun the strain would be 11½ tons per square inch.

156. Again, with the brown powder gun the effect of cutting off 6 feet of the chase would only be to decrease the velocity by about 70 feet per second.

157. Of course the guns could be constructed to suit one powder or the other, but the point to be noted is that, if the pressure curves be really such as these, there appears to be no possibility of knowing what the distribution of pressure will be in any particular nature of gun or with any particular brand of powder in that gun.

158. The assumptions which I have made regarding the pressures in the chase corresponding to different positions of

the projectile, and the derivative formulæ, fully account for the ballistic results, and the presumption therefore is that these pressures may be adopted as a safe guide to the required strength of the chase.

159. The real pressures may possibly be less than those given by the formula in the vicinity of the maximum, but they cannot possibly be greater, and it is for this reason that the latter are reliable and ought to be useful in calculating the strength of the chase of a gun.

CHAPTER V.

160. It may now be inquired what will be the probable effect of these new powders on the future of gun construction, and what the possibilities of future artillery practice.

161. It is beyond doubt that these powders must supersede ere long the old black and brown powders, and that quite independently of the advantage of their smokelessness. The most striking feature is that of their vastly superior force.

The E.X.E. powder, which till recently was considered to be the best powder for heavy guns, only gave about 60 foot-tons of energy per pound of powder in the 6-inch gun.

The Brown Prismatic gave the following energy per pound of powder :—

In 110 ton 16·25 inch gun	..	68·1 foot-tons.
„ 67 „ 13·50 „ ..	..	57·6 „
„ 29 „ 10·0 „ ..	..	61·1 „
„ 14 „ 8·0 „ ..	..	58·0 „
Average	..	61·2 „

Whilst, as shown before (§ 121), the energy in a 6-inch gun with the new powders was—

Cordite	..	254·7 foot-tons.
Nobel's Powder	..	210·5 „
French B.N.	..	152·0 „

If, therefore, the average of the brown powder be taken as unity, the strength of the others will be—

Cordite	..	4·16
Nobel's	..	3·44
French B.N.	..	2·48

162. From this it follows that the weight and size of the cartridges may be much less than with the old powders.

This is in itself a great advantage, both as regards the handling and the storage of the ammunition.

163. In the next place, it will most likely be found that the erosion of the gun will be considerably less, inasmuch as the products of combustion are almost entirely gaseous, instead of being mixed, as in the old powders, with more than half their weight of non-gaseous matter.

164. Let us now consider how gun design and construction will be affected by a change to the new powders.

To begin with, the present enlarged chambers will no longer be required.

The present 6-inch gun has a chamber of 1364 cubic inches capacity, a diameter of 8 inches, and a length of about $26\frac{3}{4}$ inches from the obturator head. It will contain 54 lbs. of E.X.E. powder, and will give to a 100 lb. projectile a velocity of 2150 feet per second, with a maximum pressure of $19\frac{1}{2}$ tons per square inch.

165. This represents an energy of 3200 foot-tons. The same energy might be given with 12·57 lbs. of Cordite, which would occupy a space of 315 cubic inches, and supposing the diameter of the chamber to be 6·4 inches, the length of the charge would be 9·87 inches.

The length of the chamber would of course be greater, and would depend upon what was fixed on as the maximum pressure.

166. Let this be fixed at 19·6 tons per square inch, the same as with the 54 lbs. of E.X.E., then the equivalent length of the chamber would be 23·18 inches. If, however, the maximum pressure were fixed at 27 tons per square inch, the equivalent length of chamber would be only 16·83 inches, or about 10 inches less than in the present 6-inch gun.*

* The equivalent length of chamber is dependent on the maximum pressure, and is determined by means of the formula (6) § 91.

167. The strains upon the breech blocks would be respectively

In the present gun with pressure	19·5 tons	..	980 tons.
In the new „ „ „	27·0 „	..	868 „

So that the extra pressure really strains the breech apparatus and the jacket less than in the present gun.

168. There are two ways in which the pressure may be modified whilst the charge of powder and weight of projectile remain unchanged.

The formula for the maximum pressure is, as shown in formula (17) § 112,

$$p = A_{,} \frac{W^{\frac{1}{2}} w^{\frac{3}{2}}}{l\, c_{,}^{4}},$$

in which if W, w, and $c_{,}$ are constant, p may be modified by an alteration of either $A_{,}$ or l.

l is the equivalent length of the chamber, and it is evident that by increasing it the maximum pressure will be reduced.

169. The factor $A_{,}$ is not an absolute constant even for powders of identical composition. It includes the form and dimensions of grain (which with Cordite is represented by the diameter) and corresponds to the factor $\frac{A}{\delta}$ in the formula (6) for Nobel powder.

Consequently, by increasing the diameter of the Cordite, the value of p will be lessened.

It therefore follows that the pressure may be decreased, either by an increase of the length of chamber, or by an increase of the diameter of the Cordite, and it may be shown that the latter method is the most advantageous as regards ballistic effect.

This it is not difficult to see from the formula itself, but it will be more evident from an example to which the formula is applied.

170. For instance, let us take the 6-inch gun of 40 calibres, and assume that the maximum pressure is to be 30 tons per square inch.

Let the value of $A_{,}$ be as before 1534, and let the

equivalent length of chamber be 37·5 inches. Then it will be found by formula (17) that to give a pressure $p = 30$ tons the weight of charge would be 21·39 lbs. of Cordite. Under these circumstances the projectile of 100 lbs. would acquire a velocity of 2839 feet per second, and a muzzle energy of 5587 foot-tons, or 261 foot-tons per pound of powder.

171. Let us now take the same gun, the same charge, and the same projectile, but suppose that by reducing the value of $A_{\prime}$ the same pressure of 30 tons is obtained in a chamber of one-half the length; it will now be found that the muzzle velocity will be 3050 feet per second, and the muzzle energy 6447 foot-tons, or 301 foot-tons per pound of powder.

172. The advantages of a high maximum pressure will, however, become more evident if we compare a gun working with the pressures now in general use in this country, or about 17 tons per square inch, with the same gun working at a pressure of 30 tons per square inch.

173. In making this comparison I will take the Nobel powder rather than the Cordite, because the published information regarding it is much more extensive.

174. Reverting again to the formula for pressure

$$p = A \frac{W^{\frac{1}{2}} w^{\frac{3}{2}}}{\delta \, l \, c_{\prime}^{4}},$$

which contains explicitly the size of the grain, it will be seen that, for a powder of the same composition, if the same projectile be used, in the same gun, the pressure varies as $\dfrac{w^{\frac{3}{2}}}{\delta l}$; consequently, by varying any one or more of these symbols we may obtain any desired pressure.

175. To illustrate this I will take the 8·24-inch gun of 35 calibres, with the following ballistic elements:—

$c_{\prime}$	λ	l	L	W	w	P	p	Π	δ
8·306	16·00	68·14	218	308·7	48·5	175	13·94	15·44	·393

Making use of formulæ (6) and (12), we find:—

Energy of projectile ..	..	8578 foot-tons
„ per lb. of powder	..	177·0 „
Muzzle velocity ..	..	2002* feet per second.
Penetration of wrought iron	..	19·13 inches.

176. If now the pressure be doubled by reducing the length of the chamber, using the same weight of charge, we get:—

Energy of projectile ..	..	13,077 foot-tons.
„ per lb. of powder	..	269·7 „
Muzzle velocity	..	2472 feet per second.
Penetration of wrought iron	..	23·61 inches.

177. In the next place, if the original length of chamber be retained, and the pressure be doubled by increasing the weight of charge, it will be found that the charge required will be 76·69 lbs., and the following will be the ballistic results:—

Energy of projectile ..	..	15,865 foot-tons.
„ per lb. of powder	..	206·3 „
Muzzle velocity	..	2723 feet per second.
Penetration of wrought iron	..	26·24 inches.

178. Lastly, if instead of the size of grain δ being ·393, we make it ·500, the weight of charge required to give the same double pressure will be found to be 90·26 lbs., and the ballistic results—

Energy of projectile ..	..	17,703 foot-tons.
„ per lb. of powder	..	196·7 „
Muzzle velocity	..	2876 feet per second.
Penetration of wrought iron	..	27·78 inches.

179. From this it is seen that the best ballistic effect is obtained by retaining the larger chamber, and increasing the weight of charge and the size of grain of the powder. Thus by increasing the working pressure in this way, we

* The observed velocity was 2005 feet per second.

have with the same gun obtained the following advantages:—

Increase in muzzle velocity	from	2002 to 2,876 feet per second.
,, ,, ,, energy	,,	8578 to 17,703 ,, ,,
,, ,, penetration	,,	19·13 to 27·78 inches.

180. This gun would weigh only 15 tons, and yet its power of penetration is within 10 per cent. of that of the 13·5 inch Woolwich gun weighing 67 tons, and is 12 *per cent. greater than the 12-inch gun of* 47 *tons.*

181. This naturally leads to the conclusion that by adopting the high-pressure system, ballistic results equal to those obtained from the existing guns may be got from much shorter guns, constructed for the new powders.

182. It may be said that in the preceding paragraphs the comparison has been made between existing guns firing the old powders and other guns firing the new powders, and this is no doubt true, but the reason is that, as I have shown elsewhere, the existing guns are too weak to permit of the high pressures which may be obtained from the new powders.

183. The effect of the length of gun will be best illustrated by an example.

What, for instance, would be the result of reducing the length of the 8·24-inch gun, above referred to (§ 177) by 5 feet?

It would reduce the muzzle velocity from 2723 feet to 2483 feet, which would still exceed that of the low-pressure gun by 367 feet per second, the total length of the gun being reduced from 24 feet to 19 feet, which is about 2 feet less than the 8-inch Woolwich gun.

184. The weights of the two guns would be about the same, whilst the muzzle energies would be about as follows:—

Woolwich 8-inch gun	7,060 foot-tons.
New 8·24-inch gun	13,190 ,,

185. In order to compare the power of guns working with the new powders at high pressure, with the present new type guns working with Brown Prismatic or E.X.E. powder, I will compare the 12-inch gun of 45 tons with a gun of the same weight and length, working with Nobel powder, at a pressure of about 30 tons per square inch, and of which the following are the ballistic elements:—

c_i	λ	l	L	W	w	δ
12·1	30·87	80	240	900	200	·500

186. The comparative results are given in the following table:—

—	Woolwich Mark V.	New Gun.
Calibre of gun (inches)	12	12
Total length over all (inches)	328·5	327
Weight (tons)	45	45
„ of projectile (lbs.)	714	900
„ „ charge (lbs.)	295 B. Pr.	200 Nobel
Muzzle velocity (feet per sec.)	1910	2517
„ energy (foot-tons)	18,060	39,537
Maximum pressure (tons per sq. in.) ..	17·5	29·69
Penetration of iron at muzzle by Maitland's formula (inches)	22·5	34·00
Do. at 1000 yds.	20·6	31·44

187. I will next give an example to show how, by the increase of pressure, the length of the gun may be reduced and yet the ballistic effect be increased, and for this purpose I will compare the present Woolwich 12-inch gun, Mark V., of 27 feet 4½ inches in length, with a proposed new gun of 20 feet 2½ inches, both firing the same weight of projectile and approximately the same weight of charge of Nobel's

powder, the Woolwich gun working under a maximum pressure of $17\frac{1}{2}$ tons, and the new gun of 29·65 tons per square inch.

188. The following table shows the results.

—	Woolwich Mark V.	New Gun.
Total length over all (inches)	328·5	242·5
Weight (tons)	45	45
Weight of projectile (lbs.)	900	900
Weight of charge, Nobel powder (lbs.) ..	148·7	147·4
Maximum pressure (tons)	17·5	29·65
Muzzle velocity (feet per sec.)	2064	2285
Muzzle energy (foot-tons)	26,589	32,571
Penetration at muzzle, Maitland's formula (inches)	27·58	30·71
Do. at 1000 yards (inches)	25·60	28·90

189. The ballistic elements of these guns are as follows:—

	$c_{\prime}$	λ	l	L	W	ω	δ
Woolwich	in. 12·1	in. 22·95	in. 87·04	in. 255	900	148·7	·500
New gun	12·1	22·80	40·00	180	900	147·4	·500

The new gun being about 7 feet shorter than the Woolwich gun, might be made very much lighter, but this would not be advisable. It would be much better to make it even heavier, say about 50 tons, putting the extra weight into the chase, so as to give a better defence against quick-firing guns of small calibre, and at the same time relieving to some extent the strain upon the gun mounting.

190. The above tables demand the most serious attention from those to whom is entrusted the armament of our forces, naval and military.

The results contained therein point to nothing less than *the entire reconstruction of our heavy armament.* If it be true that a 12-inch gun can be made, as is shown in the table § (186), to develop 39,537 foot-tons of energy, piercing 34 inches of iron, whilst the present 12-inch gun of the same weight and length can only develop 18,060 foot-tons and pierce 22·5 inches of iron, it surely is a serious question whether the present guns can be considered as efficient guns.

191. If again, a gun of 20 feet length can be made to pierce 30·71 inches of iron, whilst the present gun of 27 feet length cannot pierce more than 27·58 inches, this surely again raises the same question.

192. But, in truth, the question goes beyond this. The results shown in these tables depend on the assumption that the present guns (which certainly have no excess of strength for the maximum pressure of 17½ tons arising from Brown Prismatic or E.X.E. powder) will be strong enough for the maximum pressure arising from the new powders.

193. But this by no means follows. The new powders develop pressures in the chase of the gun, greatly exceeding those at corresponding points when the old powders are used, so that although the present guns may be strong enough to resist the pressure of 17½ tons in the vicinity of the chamber, they are much too weak in the front part of the chase to resist the pressure which would be developed at that point from the charge of 148·7 lbs. Nobel powder, which is supposed to be used in the comparison made in table, § (188).

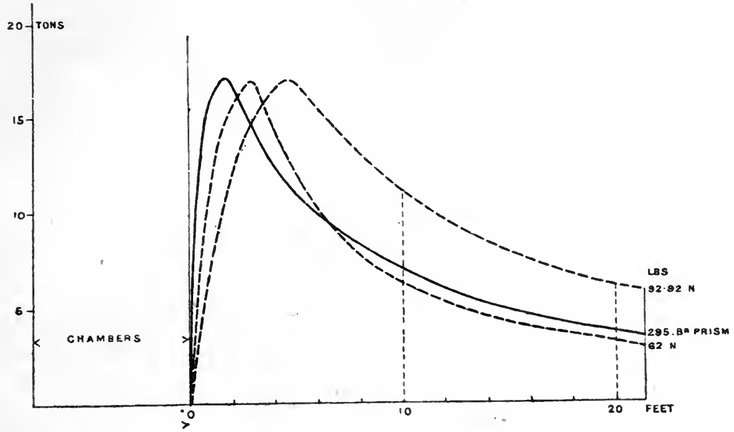
194. This will be very apparent from the following diagram, Fig. 9.

The full line shows the pressure with 295 lbs. Brown Prismatic powder. The energy as deduced from the curve is about 18,060 foot-tons, allowing 10 per cent. for resistances. This would give a muzzle velocity of 1710 feet per second with a 900 lb. projectile.

The upper dotted line shows the pressure in the same

gun with 93 lbs. of Nobel powder, which would give the same maximum pressure of 17½ tons per square inch, but would develop 23,931 foot-tons of energy and give a muzzle velocity of 1958 feet per second. It is evident that if the

Fig. 9.



gun is made to bear the pressure of the 295 lbs. Brown Prismatic it is by far too weak to bear those of the 92·92 lbs. of Nobel.

195. It may, however, be asked, what would be the pressure, if a reduced charge of Nobel powder be used, so as to give the same maximum pressure of 17½ tons and the same muzzle energy as the 295 lbs. Brown Prismatic?

196. In order to do this the charge would be 62 lbs. Nobel powder, but to obtain the 17½ tons of maximum pressure with this charge it would be necessary to reduce the size of the chamber. By formula (6) it may be found that the equivalent length of chamber with this charge, and the pressure of 17·5 tons, would be 23·42 inches, or only about one-third of the equivalent length of the chamber of the present gun.

197. With this reduced chamber and 62 lbs. charge, the pressures are denoted by the lower dotted line, which gives

the same energy and the same muzzle velocity as the 295 lbs. of Brown Prismatic.

198. It will be seen that with this low charge of Nobel powder, the chase of the present gun will be sufficiently strong, except just at about 3 feet from the end of the reduced chamber.

199. No doubt, in this case, there is the advantage of a greatly reduced weight of charge and probably a reduced erosion, but *there is no increase of ballistic effect.*

200. If the latter be aimed at, the charge of powder must be increased, and the chase will no longer be able to resist the pressure.

201. The conclusion therefore is, that with the present guns no great increase of ballistic effect will be possible with the new powder.

202. But it has previously been shown (§ 188), that with a gun properly designed for the use of high pressure, using about half the weight of Nobel powder, instead of the charge of Brown Prismatic, the ballistic effect may be raised from 18,060 to 32,571 foot-tons, although the gun is 7 feet shorter than the present 12-inch gun.

CHAPTER VI.

203. The conclusions arrived at in the preceding pages have very far reaching import. Were they mere speculative opinions they would be very suggestive, but they cannot fairly be viewed in this light. They are altogether based on calculations, the formulæ for which are given and explained.

204. These formulæ are, it is true, in some degree based on hypotheses, but the hypotheses are rational, and not imaginary, and the formulæ are shown to give results very fairly in accordance with experimental facts as regards the Nobel powder.

The experimental facts in my possession regarding the French B.N. powder and the English Cordite are too few to form the basis of an independent investigation, but I have shown that, so far as they extend, they do not disagree with the results arrived at from the Nobel powder formula.

205. These latter, be it remembered, extend to no less than 468 experiments made with powder of different brands though of the same composition, in grains varying from ·0395 inches to 0·393 inches in thickness, fired from guns of 1″·969, 2″·362, 2″·952, 3″·09, 3″·43, 3″·78, 4″·74, 5″·88 and 8″·24, with projectiles varying from 3·85 lbs. to 308·7 lbs., and charges varying from 0·35 lbs. to 48·50 lbs.

206. The constants used in the formula have been derived from a careful analysis of the whole of the 468 rounds fired from 16 different guns, and the results calculated by the formula thus constructed have been found to

agree as satisfactorily as could be expected with the actually shown results.

207. It may therefore be asserted of the conclusions arrived at, that they represent approximately the actual facts attendant on the use of the Nobel powder, and that in all probability the results from B.N. and Cordite would be very similar.

208. This being so, very grave consequences result, *no less than an entire reconstruction of our artillery.*

209. If a gun of 12-inch calibre, weighing from 45 to 50 tons, and not exceeding 20 feet long over all, can be made to pierce 31 inches of iron at the muzzle, or 29 inches at 1000 yards, then I maintain that such guns as the 110-ton gun of 44 feet, and the 67-ton gun of 36 feet must become obsolete weapons.

210. Indeed it is questionable whether even a 12-inch gun, such as has been described, is not too large for general use.

It has been shown (§ 178) that a $8\frac{1}{4}$-inch gun, weighing about 16 tons, and firing 90 lbs. of Nobel powder, will impart to a 308-lb. projectile a velocity of 2876 feet per second, and will pierce 27·78 inches of iron. Six of such guns might replace one 110-ton gun, and would give a collective muzzle energy of 106,218 foot-tons as compared with the 56,000 tons of the 110-ton gun, whilst the weight of powder used would be 540 lbs. against 900 lbs. respectively.

211. Such guns as are here proposed might easily be mounted on disappearing carriages, and would thus be comparatively safe against the attack of quick-firing guns, which will form a very important feature in the armament of the future, and by a moderate increase in the weight of the gun, by thickening the chase, they would be invulnerable to many projectiles which would put the present guns out of action.

212. The fundamental principle which is involved in such a change is the adoption of a high pressure such as

30 tons per square inch, instead of the present regulation pressure of $17\frac{1}{2}$ tons per square inch.

213. This principle I have advocated for very many years, almost single-handed—indeed, with the exception of one eminent officer, General Brackenbury, I may say quite alone. In a paper read by him at the Royal United Service Institution, 1884, on "Gunpowder considered as the Spirit of Artillery," he said, "We constantly hear that a gun has been produced which will do this or that, yet it is not the gun which does it but the gunpowder. There is not a single gun actually adopted for service in any country which is not, by its weakness, a hindrance to the full action of the Spirit of Artillery. When gun-makers say that their gun will produce a certain effect provided that a suitable powder be found for it, they mean, provided that the strength of the powder be restrained, cribbed, cabined, and confined to suit the weakness of the gun. We sometimes see in human life a great and strong spirit tear to pieces a feeble frame which contains it, and we do not say, 'What a pity that the spirit is so strong,' but rather, 'How sad that the body is so weak.' In the case of artillery we are always subduing and taming the spirit instead of strengthening the body."

214. General Brackenbury, when he used this language, was Superintendent of the Royal Gunpowder Factory at Waltham Abbey.

When I quoted his remarks at the Institution of Civil Engineers, in March 1884, Colonel Maitland, then Superintendent of the Royal Gun Factory, said that he did not agree with his fellow superintendent of the Gunpowder Factory. He said that he found that powder-makers liked very strong guns because they did not make their powder very regular or keep it under control; but he thought that they had attained with their slow burning powder a very great deal more energy per ton of gun than was ever done with the quick-burning powder. If that theory was right, why should they nct at once take to gun-cotton? That would be the next step; if they could once control that, it would be

much better than powder, taking up much less space for an equal amount of gas.

215. Now that is virtually what is being done, the smokeless powders being compounds analogous to gun-cotton, "brought under control." But how are they being dealt with? Precisely as before, by taming their spirit, keeping down their power, by using them at low pressure, and obtaining the required ballistic effect by inordinately long guns.

216. Upwards of thirty years ago I took exception to a statement made by the then Secretary of State for War, that rifled cannon required a weaker and slower powder than other guns, and remarked that such requirement could only be based on the fear that the guns were not strong enough to resist the increased strain. I have never seen reason to alter this opinion. I know that I stand opposed by the almost universal voice of gun-makers, and that my long continued endeavours to introduce a system of strong guns and high pressures have hitherto met with, to say the least, a very cool reception.

217. As regards manufacturers, it is not difficult to see why. Until the last few years there was only one, the Elswick firm, which made guns for Government. At present there are three or four others, but all these firms have expended or are expending enormous amounts in plant, which, although necessary for the production of the present forged steel guns, will to a great extent be useless for the construction of guns on the system I have so long advocated.

Were my views adopted the expense for plant requisite for a gun factory would be comparatively small, a great amount of what has been expended would be of comparatively little use, and the result would be that new gun factories, less heavily burdened with capital, would come into competition with the three or four existing companies.

It is therefore not difficult to understand why any endeavours to introduce a new system have met with little favour from ordnance manufacturers.

218. Nor is it difficult to understand why it has been so coolly received by the officials of our Ordnance Department. A pervading principle in all official departments is "quieta non movere"; but besides this is the fact, that as regards our own administration, it may well be doubted whether it is so constituted as to conduce to the real advancement of artillery science.

219. How is such a change as I have spoken of above likely to be looked on by our officials in the Ordnance Department? It is not difficult to imagine the horror with which they will regard such a proposal as another reconstruction of armament. "What!" they will exclaim; "sacrifice the magnificent forged steel guns which have cost us such enormous labour and expenditure of money to bring to perfection?"

220. It is no doubt a grievous prospect, but facts are facts however unpleasant in their aspects, and the statements I have above made represent what I believe will be in a very short time established facts.

221. If so, that nation that first recognises the truth, will most profit by it, and will be in a position relative to other nations similar to that of the Prussians armed with the needle gun in the campaign of 1866.

222. To England, as a naval power, the matter is of supreme importance, and I would that a more powerful voice than my own would insist upon the truth of my statements being brought to the proof of experience.

The great moving force in this country, public opinion, cannot be brought to bear on a question of such a technical character, and my own personal experience, extending over some thirty years, with respect to such questions, is not such as to give me any hope that anything I may say or do will avail.

223. It is more than thirty years since I first advocated the construction of strong guns, and showed how to make them, and at last it was not my own country, but Russia, which undertook to make a gun on my own principle, and from my

own designs. This gun was eminently successful, having fired 1000 rounds in 1888 with heavy charges, and other and larger guns of the same design are now being made in Russia.

224. Since then another gun of the same size has been made from my design by Messrs. Easton and Anderson, and has been for many months at Shoeburyness, used, I believe, for powder trials.

225. In fact, the practical success of the wire system is now an established fact.

It has been adopted into the service and a large number of wire guns are now being built at Woolwich, but it is probable that they will be low-pressure guns of great length.

226. Our Ordnance Department are not alone in their belief in low pressure. A very scientific officer of the French Artillery, who used to be a great advocate of the wire gun construction, wrote to me some time ago, that in his opinion, the *raison d'être* of the wire system had almost disappeared in face of the brilliant results obtained with the French smokeless powder. As regards ballistic results merely—that is to say, the energy that may be given by a given weight of powder to a given projectile—there is truth in what he says, but it is a very different thing when practical gunnery is concerned.

227. The great results they have got in France have been due to the enormous length of their new guns, guns of from 40 to 50 calibres in length, guns which I do not hesitate to say are quite unfitted for naval service, if indeed advisable anywhere.

228. My contention is, that by the use of high pressure more efficient guns can be made of very moderate length, and that in actual warfare these long guns would be nowhere at all, in the presence of the powerful short guns which I am now advocating.

229. The short guns would not only have the advantage of greatly increased ballistic power, but would be far more handy and manageable. They would also be much less vulnerable, because their chases would be much shorter and

much stronger than the slender chases of the present long guns.

230. The vulnerability of the chase of the present guns is a very serious matter indeed, and is no question of opinion. In a lecture at the United Service Institution on 18th January, 1889, it was stated by the lecturer, Captain Stone, R.A., that "at Eastbourne a shell from one of the 6-pounder Hotchkiss guns struck the chase of a 10-inch B.L. gun, and penetrated the bore; and that at Shoeburyness a 9″·2 B.L. gun was struck on the chase, and a bulge of nearly half an inch raised on the interior of the bore, thus rendering it unserviceable."

231. What, it may be asked, would be the result of the attack of a number of 4-inch or 5-inch Q.F. guns on the monster ordnance with which our new line-of-battle ships are armed?

232. It seems inconceivable to any ordinary mind that this fact is made so light of, and that these 110-ton guns and 67-ton guns are still patronised by the authorities, and still more so that they are for the most part mounted "en barbette."

The probability is, that before they had fired half a dozen rounds they would be put out of action.

233. Quite irrespective of this, the 110-ton guns are fatally defective in strength. I am not speaking now of strength to resist the bursting strain, but of strength longitudinally.

234. In a recent pamphlet on 'Smokeless Powder,' I alluded to this, and in 'Internal Ballistics' I dealt with it at some length, and as confirmatory of its importance, I alluded to the drooping at the muzzle of one of the 110-ton guns made at Elswick for the *Victoria.*

235. Since then, others of these large guns have failed in the same manner, the latest being one of those of the *Sans-pareil,* which, like the *Victoria* gun, has drooped at the muzzle after firing a few rounds.

236. When the *Victoria* gun drooped in 1890, the fact

was made light of. It was attributed by Lord Armstrong to the defect of the proof carriage on which the gun was tried at Woolwich. Lord George Hamilton, in his speech at Liverpool on 30th November, 1889, said that the gun was "not a failure, that in the unanimous opinion of his scientific and ordnance advisers, it was a perfectly safe gun. Still, it was not a perfect gun, and it would be returned to the manufacturers to be strengthened, but the manufacturers assured him that within three weeks a strengthened gun would be in their possession, and that in the next three or four months the number of guns which they had undertaken to deliver of that calibre, and strengthened upon the principle he had mentioned, would be in the hands of the Admiralty."

237. Now the *Sanspareil* gun was one of these strengthened guns. In fact it was strengthened twice. The first strengthening consisted in removing five of the second row of hoops adjoining the seat of the gun, and replacing them by a continuous hoop of about 10 feet long. This was the alteration made in the *Victoria* guns. Subsequently to this, the *Sanspareil* guns were additionally strengthened by shrinking another tube about 4 feet long over the second row of hoops, in front of the 10-feet hoop.

This gun, as well as those of the *Victoria,* has also drooped at the muzzle, and it is easy to see why.

238. The additional hoops gave to the gun no appreciable strength to resist flexure, for the simple reason that they were discontinuous with the body of the gun behind the point at which flexure began. They gave no addition to what Lord George Hamilton designated as "girder" or "cantilever" strength.

239. But the guns were never deficient in girder strength, and it was only when at the same time they were subjected to the very heavy longitudinal strain, arising mainly from the friction of the products of combustion, that the limit of elasticity of the material was passed, and the chase acquired a permanent set. The remedy for these guns would be to

take away the last tube of 48 inches long and put on an additional tube over the first tube of 10 feet long, firmly connected longitudinally with the tube containing the gun seat which replaces the trunnions. In this way the overhang of the muzzle end would be reduced by about 10 feet and the effective diameter to resist the transverse strain, greatly increased.

240. What would be still better, would be to remove these guns altogether from the ships, and utilise them for land defences, in which case, as an increase of weight is of little importance, the new tube should extend to the muzzle of the gun, being at the same time firmly locked to the tube of the gun seat. This, whilst giving longitudinal strength to the gun, would greatly increase its defensive power against the attack of quick-firing guns directed against the chase.

241. In my opinion it would be an unpardonable error to reckon on these guns as efficient weapons for the armament of battle ships.

APPENDIX.

NOTE A.

VALUE OF γ.

In my pamphlet 'Smokeless Powder,' 1890, I took for γ the value $1 \cdot 319$.

This was obtained from Nobel and Abel's formula—

$$\gamma = \frac{C_p + B\lambda}{C_v + B\lambda}$$

where C_p and C_v are the specific heats at constant pressure and constant volume respectively, a the ratio of the volume of the non-gaseous products to the volume of the unexploded powder, β the ratio of the weight of the non-gaseous and gaseous products, and λ the specific heat of the non-gaseous products.

$$a = \cdot 57 \qquad B = 1 \cdot 2957$$
$$C_p = \cdot 2324 \qquad C_v = \cdot 1762 \qquad \lambda = \cdot 45$$

This formula, when the whole of the powder is gasified, gives

$$\gamma = 1 \cdot 319.$$

The specific heats given above are those at ordinary temperatures, but it is now generally believed that they do not apply to gases at very high temperatures. It has been shown by Mallard and Le Chatelier (Comptes Rendus, vol. xciii., 1881) that the specific heat at constant volume of the gases of a Siemens furnace is $0 \cdot 34$.

Now 1 lb. of gas at 492° absolute temperature doubled in volume by heating would require

$$1 + 492° + \cdot 34 \quad = \quad 167 \cdot 28 \text{ units};$$

and if we take the volume of 1 lb. of gas to be 11·5 cubic feet, the work done against the atmosphere would be

$$\frac{11 \cdot 5 \times 2116 \cdot 4}{772} = 31 \cdot 60;$$

$$\text{Brought forward} \quad \underline{167 \cdot 28}$$

$$\therefore \text{ Specific heat at constant pressure} = \frac{198 \cdot 88}{492} = \cdot 4043$$

$$\text{and } \gamma = \frac{\cdot 4043}{\cdot 340} = 1 \cdot 189.$$

This value of γ, for which I am indebted to Dr. Anderson, is perhaps rather too small, and I have adopted the value of $\gamma = 1 \cdot 2$ provisionally, which appears to give satisfactory results.

NOTE B.

THE INFLUENCE OF THE MODE OF IGNITION.

Although the formula (5) is found to agree fairly well with the results of experiments, it must be remembered that all these experiments were made so far under like conditions that the form of grain, the mode of ignition, and the composition of the powder were probably the same.

But M. Sarrau has shown that the form of grain is a factor in the formula for pressure, and is contained in the symbol a in $\left(\frac{fa}{\tau}\right)^{\frac{1}{2}}$ which is M. Sarrau's "characteristic" a. f, also, is dependent on the composition and mode of fabrication of the powder, so that both of them are involved in the symbol A in my formula.

These, however, were probably the same, or nearly so, in the powder used in Krupp's experiments, so that the value obtained above for A is probably nearly correct for that powder.

There is, however, another element which ought not to be neglected, whilst it may not be possible to express it explicitly in the formula, but which must not be ignored in comparing the pressures obtained under conditions which are not identical. This is the mode of ignition of the charge.

In my treatise on 'Internal Ballistics' I dealt with this at some length. I will now only briefly point out how the maximum pressure may be affected by differences in the mode of ignition.

If the charge be ignited at the end only, it is obvious that the rise of pressure will be slower than if the ignition be simultaneous throughout, and the maximum pressure will be less because the projectile will have had more time to move away, and thus increase the space filled by the gases.

There are two methods of ignition in practical use, the electric and the detonator, but in reality these are but one, since the electric is only a means of igniting a detonator, which then ignites the cartridge.

But the effect of a detonator varies according to its strength and according to the way the cartridge is made up. With a weak detonator and a cartridge closely packed, the ignition begins at one end, and proceeds comparatively slowly through the charge, and the pressure is correspondingly low. On the other hand, with a powerful detonator and a cartridge loosely packed, or with a central void, the ignition is nearly instantaneous, and the resulting pressure high; and indeed, with any cartridge however made up, the ignition will always be quicker with a powerful detonator, resulting in a higher pressure and a greater muzzle velocity.

It is therefore evident that the mode of ignition, although it cannot be explicitly expressed in a formula, must not be disregarded in comparing ballistic results obtained by experiment, and consequently in the deduction of the data of a formula from experimental results the conditions of firing must be uniform.

Except in the case when the gun is to be fired from a distance, I do not understand the advantages of electric firing over a simple percussion arrangement, which appears to be equally effective, simpler, and less liable to derangement.

In all cases where the firer stands by the gun, and especially in quick-firing guns, pulling a trigger seems to be quite as rapid and easy as completing a circuit.

As, however, my experience in firing guns is very limited, I merely give this as an opinion which seems to have in its favour simplicity of apparatus and certainty of action.

NOTE C.

ON DISSOCIATION.

To what extent the pressures in the chase of a gun are influenced by Dissociation is a question which I cannot pretend to decide.

The laws of Dissociation are very imperfectly known, and as my own acquaintance with the subject is very limited it is with much diffidence that I venture to make a few observations on their probable influence on ballistic science.

A recent number of the 'Revue Générale des Sciences Pures et Appliquées,' 28th Feb., 1891, contains an interesting article by M. Le Chatelier, a portion of which I will briefly summarise. He divides chemical science into two branches, the first based upon the law of definite proportions, which he calls "Architecture chimique," and which leaves on one side such intermediate phenomena as take place when a chemical system, such as a mixture of oxygen and hydrogen, passes into another state such as water.

In the other branch, which he terms "Mécanique chimique," these intermediate states are dealt with, and the conditions under which the succession of such states are realised, and in this point of view it may be considered as the *Science of Displacement and of the Transformation of Energy.*

M. Le Chatelier states that every chemical system, whether homogeneous or not, is classed necessarily, from the mechanical point of view, in one of the three following states:—

1st. State of chemical rest.
2nd. „ „ equilibrium.
3rd. „ „ movement.

The state of chemical movement is that of a system in which the transformations take place spontaneously.

The distinction between the states of rest and of equilibrium is a comparatively recent notion, and upon it the new branch of chemical science depends.

At first sight the study of the conditions under which chemical changes take place seems to point to the impossibility of classifying and co-ordinating their conditions. Chemical reactions may be produced by circumstances of the most diverse and varying

nature. Such are, variations of pressure, of temperature, of electrical state, radiation of light, shocks, friction, and even the influence of living organisms. And not only are these causes varied in nature, but their effect is also variable, and in some cases apparently contradictory, as for example in the case of heat, which at one time determines the combustion of oxygen and hydrogen, and at another decomposes the resulting compound, water, into its elements, oxygen and hydrogen.

Such contradictions are, however, only apparent, and disappear when the direct causes of chemical changes are distinguished from those which are indirect and occasional.

This may be illustrated by an example borrowed from mechanics. Take for example the action of a pile-engine. The action of pulling the trigger releases the ram, and thus makes effective the force of gravity which causes its fall. The pulling the trigger and the force of gravity are two distinct forces which are necessary to the action of the machine: the one renders the motion possible, the other is the effective force. As long as the first does not act the ram does not move. It is at rest, not simply because it has no motion, but because no increase of the force of gravity will put it in motion so long as its intensity is insufficient to destroy the trigger mechanism.

Speaking generally, the state of rest in mechanics is due to the fact that the *active forces* are inferior to the *passive resistances.*

Now this applies also to chemical action. In chemical systems there are resistances or internal relations, the real nature of which is unknown, but which are made manifest by the obstacles which they oppose to chemical transformation. It is thus that hydrogen, carbon, and other organic matters do not combine with the oxygen of the air at low temperatures, although the stable conditions of these systems at these temperatures are water and carbonic acid.

The most part of the actions above mentioned, such as variation of pressure, of temperature, &c., have for their effect the overcoming the internal relations which oppose chemical transformation. Thus an elevation of temperature of about 1000° Fahr., in the presence of spongy platinum, transforms the mixture of oxygen and hydrogen into water, and the influence of the solar ray transforms a mixture of hydrogen and chlorine into hydrochloric acid.

The actions which are thus followed by chemical transformations cannot be called the *causes* of these transformations, because having once overcome the internal resistances they cease to operate,

and the energies which put them in action have no determinate relation with the energies displayed by the chemical changes, and are for the most part negligible with respect to these, just as the force which pulls the trigger is negligible with respect to the energy acquired by the fall of the ram.

The chemical resistances do not in every case prevent the transformation. Sometimes they only retard and limit the speed of the reaction. This varies to a great extent. In compound explosions the rupture of the internal relations is very quick. In other systems the transformation takes place rapidly at a high temperature, and very slowly at a low temperature; but in no case can the transformation take place unless the factors which determine it exceed the internal resistances. We have seen that under the influence of certain agents, such as heat, light, &c., a chemical system changes from a state of rest to that of movement.

Let us now inquire what, in the present state of our knowledge, are the powers, that is to say, the direct causes of chemical phenomena.

As regards a *change of state*, such as the vaporisation of water, the fusion of ice, these causes are well known. They are variations of pressure, heat, and electrical conditions.

Now, according to M. Le Chatelier, these are the causes, and the sole causes which intervene in chemical reactions.

The experiments on Dissociation have simply extended to chemical systems the laws of change of state. "Dissociation" shows that the true causes of chemical transformation are the variations of heat, pressure, and electrical conditions.

So long as these remain constant, a chemical condition, even if free from all internal relations, will undergo no change; but so soon as any one of these quantities varies, a chemical transformation takes place, and the quantity of matter transformed depends solely on the amount of such variation.

Pressure, temperature, and electromotive force are the three factors or causes of chemical changes by Dissociation, and these factors are included by M. Le Chatelier under the term *Tensions*, thus generalising the signification of the word, usually applied to the effect of elastic deformation by extension.

We thus arrive at the idea of chemical equilibrium, as distinct from that of chemical rest.

In the latter case it is a finite variation of tension which gives rise to chemical transformation, whilst in the former the smallest variation of pressure, temperature, or electromotive force suffices

to produce a chemical modification of the system. Thus Dissociation involves the idea of chemical equilibrium, as distinguished from the state of chemical rest.

Following this order of ideas, it would appear that such compounds as watery vapour or carbonic acid are, as chemical systems, at rest; that by increasing the heat, the internal resistances or relations are overcome, and that at a certain temperature, which is about 1100° C. for these compounds, the state of equilibrium commences, and with it Dissociation, and that thereafter the degree of Dissociation goes on increasing with the increase of temperature.

I will now inquire what would be the effect of Dissociation on the pressure in a gun with Nobel's powder, and for this purpose will assume that the deductions arrived at in Appendix A of 'Smokeless Powder' are correct, viz.:—

PRODUCTS OF COMBUSTION OF 100 GRAMMES.

	Volume at 0° C. and ·76.	Weight in grammes.
	cub. decimetres.	
Carbonic acid	20·87	41·26
Watery vapour	31·31	25·24
Nitrogen	11·04	13·86
Chlorine	8·21	16·64
Oxygen	2·08	2·96
	73·51	100·00

If now the watery vapour be decomposed into oxygen and hydrogen, and the carbonic acid into carbonic oxide and oxygen, and the various elements multiplied by their respective specific heats at constant volume, we get the following results:—

	Before Dissociation.	After Dissociation.
Carbonic acid ..	41·26 × ·172 = 7·097	$\left\{\begin{array}{l}26·25 \times ·174 \\ 15·05 \times ·155\end{array}\right\}$ = 6·900
Watery vapour ..	25·24 × ·337 = 8·506	$\left\{\begin{array}{l}22·10 \times ·155 \\ 3·14 \times 2·331\end{array}\right\}$ = 9·941
Nitrogen	13·86 × ·173 = 2·398	13·86 × ·173 = 2·398
Chlorine	16·64 × ·086 = 1·431	16·64 × ·086 = 1·431
Oxygen	2·96 × ·155 = 0·459	2·96 × ·155 = 0·459
	100·00 = 19·89	100·00 = 21·123
Mean specific heat	·1990	.. .. ·21123

And since the temperatures are inversely as the specific heats,

$$C_d = t \frac{\cdot 1990}{\cdot 21123} = \cdot 9403,$$

where t_d is the temperature after Dissociation;
t „ „ before „
so that the result of complete Dissociation is to reduce the temperature about 6 per cent.

We have next to consider the effect as regards Volume.

Since 2 vols. of carbonic oxide + 1 vol. of oxygen produce 2 vols. of carbonic acid,
and 2 vols. of hydrogen + 1 vol. oxygen = 2 vols. of watery vapour,
we get the following result:—

	Before Dissociation.	After Dissociation.
	cub decimetres.	
Carbonic acid	20·87	30·50
Watery vapour	31·31	46·96
Nitrogen	11·04	11·04
Chlorine	8·21	8·21
Oxygen	2·08	2·08
	73·51	98·79

So that the Volume is increased from 73·51 to 98·79, or from 1 to 1·344.

The combined effect of Dissociation is therefore to increase the Volume by 34·2 per cent., and to decrease the Temperature by 6 per cent.

If, then, the Temperature be assumed at 2200° C. before Dissociation, it will be 2068° C. after; and since the expansion is ·003 for 1° C., the relative volumes will be

Before Dissociation .. $1 + \cdot 0037 \times 2200 = 9 \cdot 140$;
After „ .. $1 \cdot 344 + 0037 \times 1976 = 10 \cdot 826$;

and if p be the pressure before,

p_o „ „ after Dissociation,

$$p_o = p \frac{10 \cdot 826}{9 \cdot 140} = 1 \cdot 184;$$

or the pressure is increased by 18·4 per cent.

But it was stated by Dr. Siemens in the discussion on Mr. Clerk's paper on Gas Engines, published in the 'Minutes of Proceedings of the Institute of Civil Engineers,' vol. lxix., that St. Clair Deville had determined that whilst Dissociation of Watery Vapour began at about 1100° C., only one-half was dissociated at 2800° C., which is in accordance with the remarks of M. Le Chatelier referred to above. Perhaps, therefore, it may be assumed that at 2200° C. the amount of Dissociation would not exceed $\cdot 5 \times \frac{2200}{2800}$, or $0 \cdot 38$ per cent.; and if this be so, the increase of pressure would not equal $18 \cdot 4 \times \cdot 38 = 6 \cdot 992$ per cent.

This, however, is on the assumption that Dissociation is governed only by Temperature, but, as M. Le Chatelier shows, there is also the factor of pressure, and an increase of this factor acts in a contrary direction to increase of Temperature, so that with the enormous pressures in a gun it may fairly be doubted whether Dissociation takes place at all.

There is also the question of time to be considered. It was pointed out in a note to § (35) that the time between the ignition and that of the maximum pressure in a 24 cm. gun was from $0'' \cdot 002$ to $0'' \cdot 003$, and it may well be doubted whether in this brief space of time the Dissociation could operate.

It appears certain that the chemical elements must pass through the intermediate temperatures before arriving at that of Dissociation, so that carbonic acid and watery vapour would first be formed, and then afterwards dissociated; and all this must take place in the small fraction of a second given above.

The subject is one with which I am not familiar, and I therefore offer the above remarks to the appreciation of artillerists with every reserve.

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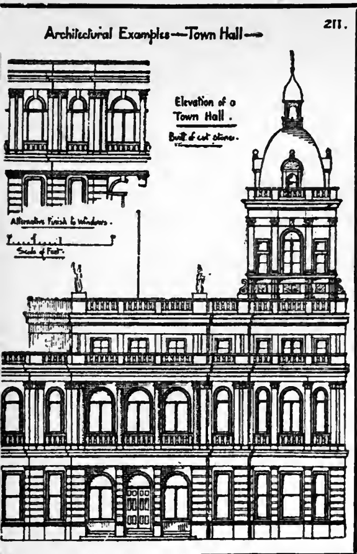

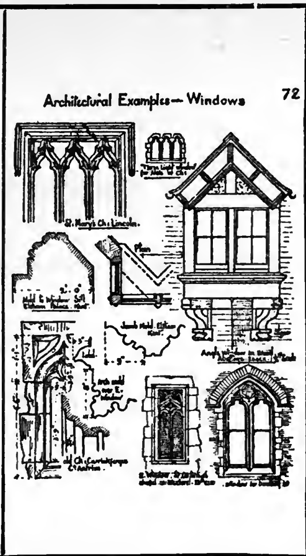

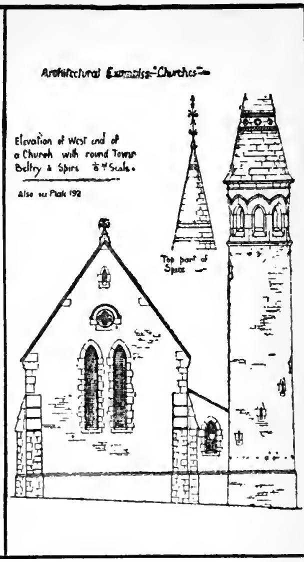

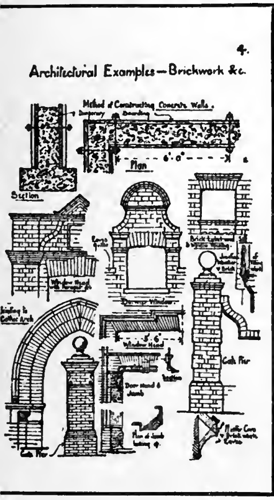

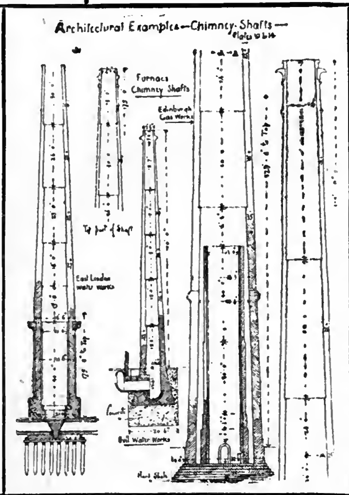

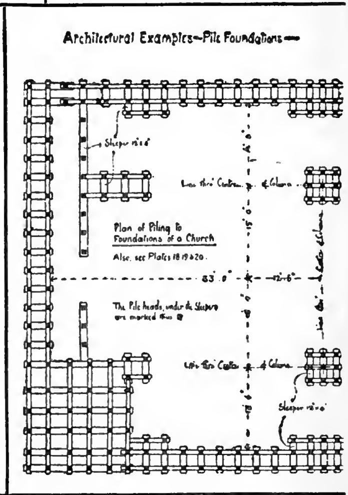

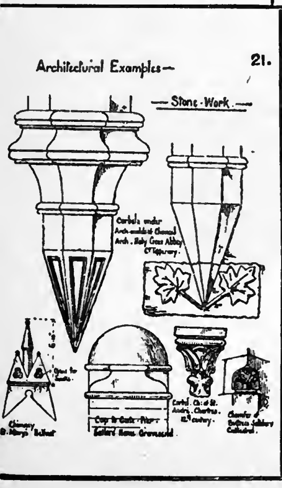

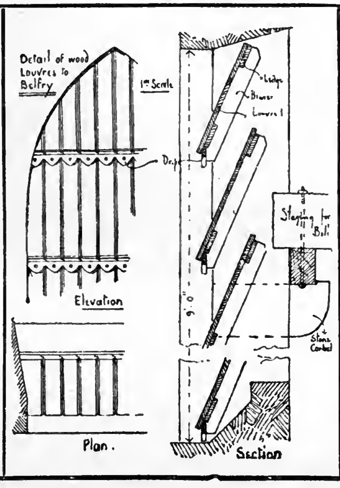

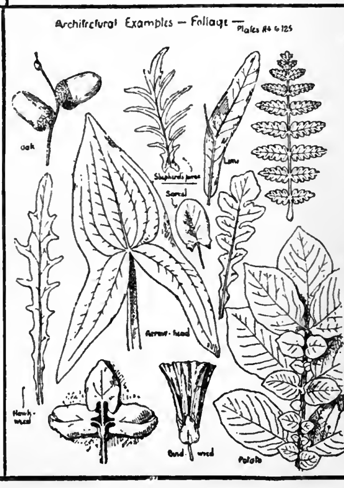

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